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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY.

SESSIONS

MDCCCLXXXVIII.-LXXXIX.—MDCCCLXXXIX.-XC.—
MDCCCXC.-XCI.—MDCCCXCI.-XCII.—
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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY,

SESSION 1888-89.

INAUGURAL ADDRESS.

I.—*Darwin's Geological Work.* By RALPH RICHARDSON, W.S., F.R.S.E., *Vice-President of the Society.*

(22nd November 1888.)

THE most important and the most charming scientific publication of last winter was the "Life of Charles Darwin." That work divided itself into three parts—Darwin's Autobiography, Darwin's Biography by his son Francis, and the letters which passed between Darwin and his more celebrated correspondents, such as Lyell, Hooker, Huxley, and others. Taken as a whole, the work placed the greatest scientific figure of modern times before us in a manner which was not only complete, but as Darwin was never placed before, because, owing to his constant ill-health and his modest retiring nature, he was little known personally beyond the limited band of scientific friends who visited him at his country residence. And what did this work reveal Darwin personally to be? It showed him to be a man of the most sterling and lovable character, a good father, a faithful friend, a hard-working man of science, whom no obstacle could discourage, no fame intoxicate, a man who had but one wish and one resolution—to discover and tell what he conscientiously believed to be the truth. That modesty which is said to be inseparable from true greatness was admirably displayed in all that Darwin wrote or said, whilst that gentleness which is considered to be essential to true Christianity was apparent in all that Darwin thought or did. Taken altogether, the bitterest opponent of Darwin's scientific opinions must, I feel sure, rise from the perusal of this work with the conviction that personally

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Darwin possessed one of the most perfect characters ever displayed. Notably his love of truth, his determination to exhaust every channel in his pursuit of it, and his readiness to fling aside the most cherished theory if he thought it lacked it, stand prominent features in the noble character of Darwin.

Darwin is best known as a great naturalist. He was also a great geologist. In the course of his correspondence we find how much, especially when a young man, he loved geology. He thought it was the most attractive and mind-enlarging of all the sciences. He recommended all his young friends to join in its study if they wished to enjoy thoughts of the largest and widest character. "It creates," he wrote, "the same grand ideas respecting this world which astronomy does for the universe." Again: "There is so much larger a field for thought (in geology) than in the other branches of natural history." This enthusiasm for geology Darwin did not, alas! acquire at the University of Edinburgh,[1] where he was, as Prof. Judd says,[2] "repelled by the narrow and soulless system of *Geognosy* taught by Jameson," but it was afterwards, when at Cambridge, he came under the spell of Henslow, a man of most catholic taste, extensive acquirements, and widest sympathy with all branches of natural science, that "Darwin's flagging interest in science was rekindled and kept alive." I pass over his student days at Edinburgh (where he was evidently much busier than he admits) and Cambridge, and proceed to the first official appointment he held.

When quite a young man, Darwin sailed as naturalist on board H.M.S. *Beagle* for South America and Australasia, and geologised zealously wherever he landed. His "Journal of Remarks" on that voyage, which lasted from 1832-36, was published in 1839, when Darwin, who was only twenty-nine years of age, had attained the proud position of Secretary to the Geological Society of London. I shall, in my address this evening, shortly describe some of the leading features of Darwin's geological work—first when naturalist on board the *Beagle*, and afterwards when he returned to England.

Darwin's Journal when naturalist on board the *Beagle* is one of his most interesting works. He was very young then, yet, as truly as "The child is father of the man," we can trace in the enthusiastic young man observing with extraordinary minuteness everything that Nature presented, the future greatest naturalist

[1] Still it was, as Mr Grant Allen remarks, at Edinburgh that Darwin "gave the earliest distinct evidence of his definite scientific tastes by contributing to the local academic society a paper on the floating eggs of the common sea-mat, in which he had even then succeeded in discovering for the first time organs of locomotion." The house (No. 11 Lothian Street) where Darwin resided when a student at Edinburgh University is now marked by a tablet which I have had erected.—R. R.

[2] Presidential Address, Geological Society, London, February 1888.

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of his times. There is a freshness and enthusiasm about the Journal which tells of the youthful Darwin, then possessed of excellent health and high spirits, ranging for the first time amid splendours of Nature of which formerly he had only dreamed. It is a book which should have peculiar claims upon us, for in it he especially records observations on the geology of the places touched at, and also advances and champions several theories of the greatest geological importance. Let me refer first to his theory of the elevation of the land around South America.

When the *Beagle* arrived off the coast of Patagonia, Darwin observed that the line of coast there consisted of a succession of terraces rising one above another. The terraces occasionally numbered from seven to eight, and included heights between 1200 feet and the level of the sea. "When any broad valley enters the country," he adds, "the terraces sweep round and run up on each side, in which case the correspondence on the opposite sides is beautifully illustrated." He gives a representation of them,[1] from which we see that the terraces consisted of gravel, &c., reposing on the strata of the coast. One of the terraces figured is 100 feet above the level of the sea, the next is 250 feet, the third is 350 feet, and the highest is 580 feet. Darwin confesses himself at a loss to understand how these terraces were formed until he referred to Lyell's "Principles of Geology," the first edition of which was published in 1833, or one year preceding Darwin's visit to Patagonia. Turning to that edition,[2] we find that Lyell notes certain sea-cliffs in Sicily as furnishing proof of successive elevation. Darwin adopted this theory for the sea-terraces of Patagonia. "There are proofs," he says, "that the whole coast has been elevated to a considerable height within the recent period; and on the shores of the Pacific, where successive terraces likewise occur, we know that these changes have latterly been very gradual."[3]

The theory adopted by Darwin to account for the formation of these successive sea-terraces rising one above the other on the Patagonian coast, is that enunciated by Lyell, viz., periods of elevation followed by periods of quiescence. "These changes," says Darwin, "all result from the assumption of a steady but very gradual elevation, extending over a wide area, and interrupted at long intervals by periods of repose." I may remark, parenthetically, that in 1884 I read a paper before this Society, in which I adduced the same theory to account for the formation of River Terraces,[4] and I have a letter from

[1] "Narrative of Voyage," vol. iii. p. 202. London, 1839. See Plate I.
[2] Vol. iii. p. 111.
[3] "Narrative," p. 204.
[4] "On the Terraces occurring on the Banks of the Tay and its Tributaries." "Edin. Geol. Soc. Trans.," vol. v. p. 56.

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Sir Herbert Maxwell, M.P., who says that, in company with Dr John Evans, he examined the raised River gravels[1] along the Somme at St Acheul and Amiens, &c.; and he thought it would be hard to account for these terraces except by Lyell's theory.

When the *Beagle* had rounded Cape Horn, Darwin found the same evidences of elevation on the western as on the eastern coast of South America. At Coquimbo he spent several days examining the step-formed terraces of shingle, first described by Capt. Basil Hall,[2] whilst at Guasco the phenomenon of parallel terraces was very strikingly seen, no less than seven perfectly level but unequally broad plains ascending by steps, and occurring on one or both sides of the valley. "The origin of the terraces of Coquimbo," he says, "is precisely the same, according to my view, with that of the plains of Patagonia; the only difference is, that the plains are rather broader than the terraces, and that they front the Atlantic Ocean instead of a valley,—which valley, however, was formerly occupied by an arm of the sea, but now by a fresh-water river. In every case it must be remembered that the successive cliffs do not mark so many distinct elevations, but, on the contrary, periods of comparative repose during the gradual, and perhaps scarcely sensible, rise of the land."

In a paper which he read before the Geological Society of London in 1838,[3] Darwin enters into further details regarding the elevation, particularly of the coast of Chili. He showed that recent marine shells are scattered abundantly to the height of about 100 feet, and he thought the land on the coast of Chili has risen, though insensibly, since 1822. In support of this gradual rise, independent of earthquakes, he stated that the eastern coast of South America bordering on the Atlantic, from the Rio Plata to the Strait of Magellan, presents terraces containing recent shells; yet in the provinces near the mouth of the Rio Plata earthquakes are never experienced.

I now come to perhaps the only piece of geological work which Darwin afterwards regretted. I refer to his theory of the formation of the Parallel Roads of Glen Roy. Fresh from abundant evidences of elevation on the coast of South America, it is not surprising that when Darwin went (as so many *savants* have done) to find a theory for the sphinx-like Parallel Roads, he should at once apply the theory which did duty in South America to Glen Roy. Consequently, in a paper which he read before the Royal Society

[1] The higher-level alluvium rises to 100 feet above the plain at Amiens. Lyell's "Antiquity of Man," 4th ed., 1873, p. 178.

[2] "Narrative," p. 423.

[3] "Geol. Soc. Pro.," ii. 1838, pp. 446-9.

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of London in 1839,[1] we find him maintaining that the roads are of marine origin. In fact, his first conclusion is that it is admitted by everyone that the horizontal shelves are ancient beaches. 2nd, No lake theory could be admitted on account of the overwhelming difficulties in imagining the construction and removal at *successive* periods of *several* barriers of immense size, whether placed at the mouths of the separate glens or at more distant points. 3rd, A sheet of water *gradually subsiding* from the height of the upper shelves to the present level of the sea, occupied for long periods, not only the glens of Lochaber, but the greater number of, if not all, the valleys of this part of Scotland. 4th, The above change of level in Scotland, independently attested by marine remains at considerable heights on both the eastern and western coasts, implies the elevation of the land, and not the subsidence of the surrounding waters. 5th, There would be intervals of rest in the action of the subterranean impulses. 6th, If the land were subjected to the above conditions, it would be found modelled in a manner wholly similar to the structure of the valleys of Lochaber as they now exist, many points in detail being explicable on the supposition that the valleys had been occupied by arms of a sea subject to tides, and which had gradually subsided during the rising of the land. Having thus considered the marine origin of the parallel roads demonstrated, he says, "I may add, that in South America I have observed numerous instances of terraces in every respect similar to these, with sea-shells abundantly scattered on their surface, and therefore where there could exist no obscurity regarding their origin.

Until Darwin became a convert to the views of Agassiz regarding the Parallel Roads of Lochaber, he maintained the marine theory which I have just detailed. In doing so he did battle with our President, Mr Milne-Home, who, in 1847 (he was then Mr Milne), criticised Darwin's theory in a paper which he read before the Royal Society of Edinburgh,[2] a criticism which affected Darwin considerably, for he wrote to Sir Joseph Hooker that he was very unwell, "Mr Milne having attacked my theory, which made me horribly sick." Another opponent (although certainly not on marine grounds) was Robert Chambers, who had visited Glen Roy with our President. Chambers criticised Darwin's theory in his "Ancient Sea Margins," in a manner which Darwin considered rather arrogant, and which he accordingly resented, as his letters to Lyell show.[3]

The upshot of the whole affair was that Darwin ultimately

[1] "Philosophical Trans.," 1839, pp. 39-82.
[2] "Transactions," vol. xvi.
[3] "Darwin's Life," vol. i. p. 362.

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abandoned his theory that the Parallel Roads are ancient sea beaches. In his Autobiography[1] he tells us that during 1837 and 1838 he acted as one of the Honorary Secretaries of the Geological Society of London. He then continues: "During these two years I took several short excursions as a relaxation, and one longer one to the Parallel Roads of Glen Roy, an account of which was published in the 'Philosophical Transactions.' This paper was a great failure, and I am ashamed of it. Having been deeply impressed with what I had seen of the elevation of the land in South America, I attributed the parallel lines to the action of the sea; but I had to give up this view when Agassiz propounded his glacier-lake theory. Because no other explanation was possible under our then state of knowledge, I argued in favour of sea-action; and my error has been a good lesson to me, never to trust in science to the principle of exclusion."

This was not, however, the only instance of (what Chambers called) the "mobile South American Continent" furnishing Darwin with a theory founded on the mobility of the land surface. We must return to his voyage in the *Beagle* to witness the origin of his celebrated theory to account for the formation, structure, and distribution of Coral Reefs. When the *Beagle* arrived in view of the Keeling or Cocos Islands, situated in the Indian Ocean, and about 600 miles distant from the coast of Sumatra, Darwin paid particular attention to the formation of the islands, as they were wholly composed of coral. "Such formations," he exclaims, "surely rank high amongst the wonderful objects of this world. . . . Throughout the whole group of islands, every single atom, even from the smallest particle to large fragments of rock, bears the stamp of having been subjected to the power of organic arrangement. Captain Fitzroy, at the distance of but little more than a mile from the shore, sounded with a line 7200 feet long, and found no bottom. This island is therefore a lofty submarine mountain, which has a greater inclination than even those of volcanic origin on land."[2]

Darwin then proceeds to give his now well-known theory for the formation of coral reefs, which he briefly recapitulates as follows: "In the first place, reefs are formed around islands, or on the coast of the mainland, at that limited depth at which the efficient classes of zoophytes can live; and where the sea is shallow, irregular patches may likewise be produced. Afterwards from the effects of a series of small subsidences, encircling reefs, grand barriers, or lagoon islands, are mere modifications of one necessary result. Secondly, it can be shown on the above

[1] "Darwin's Life," vol. i. p. 63.
[2] "Narrative," p. 554.

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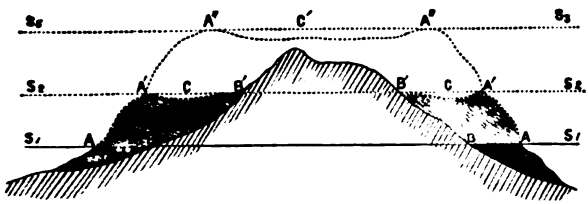
views, that the intertropical ocean throughout more than a hemisphere, may be divided into linear and parallel bands, of which the alternate ones have undergone, within a recent period, the opposite movements of elevation and subsidence. Thirdly, that the points of eruption seem invariably to fall within areas subject to a propulsion from below."[1]

The theory thus advanced was elaborated in Darwin's book on the "Structure and Distribution of Coral Reefs," and is well expressed by Professor James Geikie in his "Outlines of Geology,"[2] who describes it as follows: "A beautiful theory was advanced by Mr Darwin to account for the existence of such reefs. According to him each atoll (or coral island) has passed through the successive stages of fringing reef and barrier reef. As reef-building corals do not flourish at greater depths than 100 feet, it is evident that the foundations of a coral reef could not have been laid in deeper water. Now, as such moderate depths occur only round islands and off the shores of continents, the reef builders would begin their work by forming at first a *fringing reef*. Slow subsidence of the sea bottom is supposed to have supervened, but while the foundations were being carried down the corals continued to grow upwards, the building of the reef keeping pace with the sinking of the sea-bottom. Thus by and by the fringing reef is converted into a *barrier reef*. We have now only to suppose that the movement of subsidence and the labours of the corals continue until the reef-encircled island disappears below the waves, and a complete *atoll* will be the final result."



DARWIN'S THEORY OF CORAL ISLANDS.
AB, AB. Fringing Reef encircling an island while the sea level is at S_1 S_1.
A'B', A'B'. Barrier Reef, with Lagoon C, with the sea level at S_2 S_2.
A"A", A"A". Atoll with Central Lagoon C' over site of drowned island, the sea level being at S_3 S_3.

The most prominent opponents of this theory are Dr John Murray of the *Challenger* Expedition, and Dr Guppy. Dr Murray points out, to quote Professor Geikie again, "that all the islets surrounded by coral reefs are of volcanic origin, and that no trace of any general subsidence, such as Darwin's theory requires, can be detected. If it were true that coral reefs

[1] "Narrative," p. 569. [2] London, 1886, p. 97.

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are monuments marking the site of continental islands or masses of land, surely the islets that still remain unsubmerged, fringed and ringed with reefs, might be expected to contain other kinds of rock than volcanic lavas and tuffs. Dr Murray thinks it most probable therefore that the reefs have simply been built up from the tops and slopes of submerged and partially submerged volcanic banks and mountains." According to him, atolls "have grown upwards from the tops of submarine banks. Fringing reefs, he believes, are converted into barrier reefs by the simple growth of the coral, and do not require any process of subsidence to explain them. They simply grow outwards upon a talus of their own debris, which is forced off from the edge of the reef by the breakers."[1] But, says Professor Geikie, "although this theory does away with the necessity of any such widespread subsidence as Mr Darwin desiderated, it does not forbid the probability that some, perhaps many, coral reefs may have originated in the manner supposed by the latter."

Dr Archibald Geikie, in his "Text Book of Geology,"[2] also eulogises Darwin's theory as a "simple and luminous explanation of the history of coral reefs," and states that Darwin's views were "universally accepted by geologists" until Dr Murray threw doubts upon a theory which demanded such vast oceanic subsidence. Dr Geikie explains, but does not champion, Dr Murray's theory. It is evident that the two rival theories are at present upon their trial, and that the obvious objection to Dr Murray's theory that it "requires the existence of so many volcanic peaks just at the proper depth for coral growth, and that the number of atolls is so great,"[3] may be set against the objection to Darwin's theory, which demands vast oceanic subsidence. Dr Murray's theory was announced in a paper read before the Royal Society of Edinburgh in 1880.[4] A most valuable criticism of Darwin's theory of subsidence as affecting coral reefs (with maps), by Dr Guppy, appeared in the "Scottish Geographical Magazine" for March 1888.

At the meeting of the British Association (at which I was present) last September, at Bath, the subject of the formation of coral reefs was discussed at a special and crowded joint meeting of the Geological and Biological Sections. Both Professors Boyd-Dawkins and Seeley championed Darwin's views, whilst the leading speaker, Dr Hickson, who had studied coral reefs in the Pacific, said: "For the present, I must consider myself an adherent of the views of Dr Murray, but feel doubtful about two points—(1) Whether the force

[1] Geikie's "Outlines," p. 99.
[2] London, 1882, p. 466.
[3] Geikie's "Text Book," p. 468.
[4] "Pro. Roy. Soc. Edin.," 1880, p. 505.

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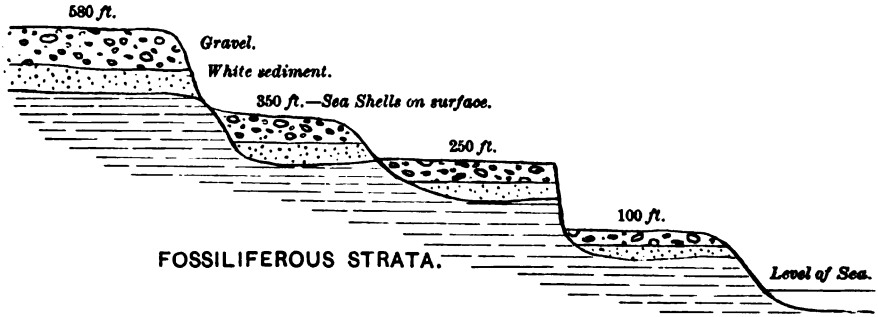
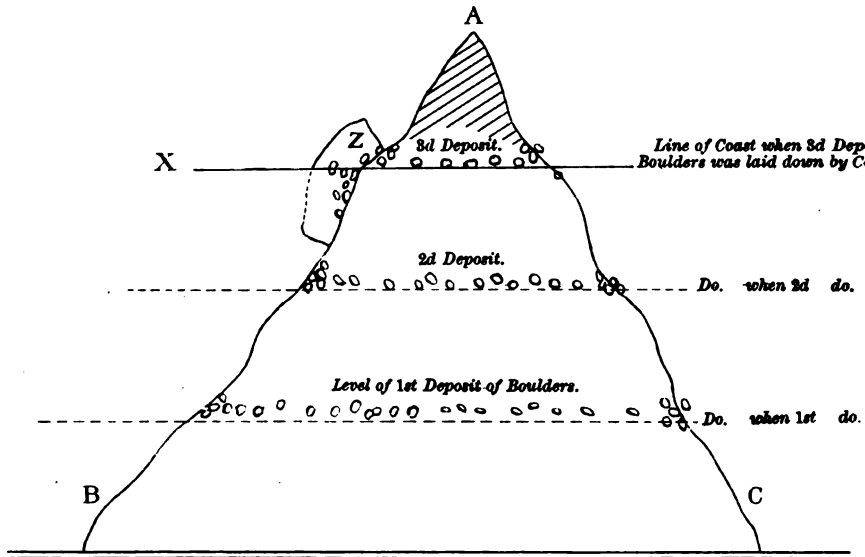


DARWIN'S SKETCH OF THE PATAGONIAN TERRACES.

The only illustration in his Journal on board the "Beagle" except two small woodcuts.



DARWIN'S THEORY OF THE TRANSPORT OF BOULDERS.

A. B. C. *Land sinking gradually beneath the Sea, the level of which remains constant at* X.
Z. *Iceberg depositing Boulders on Coast line.*

NOTE.—When subsequently the land was raised, the 2d and 3d deposits would probably be high above the sea-level, and possibly be higher than the rock *in situ* from whence the boulders were originally derived.

M'Farlane & Erskine Lith^rs Edin^r

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of solution of sea water is sufficient to account for the formation of lagoons; and (2) Whether, in some cases, such as the eastern part of the Fiji Archipelago and the Low Archipelago, the theory of subsidence may not be the correct one. Another speaker, Mr Stephen Browne, stated, from his observation of coral reefs, that he had come to the conclusion that the conditions of coral life were so complicated as to require a great deal of further observation before any theory could be formulated. We thus see that there is still a very great variety of opinion upon this interesting subject.

Although Darwin's memorable voyage in the *Beagle* influenced his intellectual life ever after (and alas! shattered his health as well), yet, arrived in England, he had to turn his attention to observations of British phenomena. I have already referred to his visit to Glen Roy. He likewise did some excellent palæontological work, his Monograph of Fossil Lepadidæ (barnacles) being printed by the Palæontographical Society in 1851, and his Monograph of Fossil Balanidæ (acorn shells) by the same Society in 1854. Darwin also studied glacial phenomena with success. In 1842 appeared his article on the Ancient Glaciers of Wales,[1] occasioned by a paper which Dr Buckland had read before the Geological Society. Darwin describes a series of mounds in North Wales covered with hundreds of large blocks of stone, which he regards as Moraine mounds. He refers to Agassiz's work on Glaciers, and says some of the Welsh phenomena might have served as models for some of the plates in the work. He likewise notices boulders described in the till of Edinburgh by Charles Maclaren,[2] and says the Welsh boulders were not, like the Edinburgh ones, "scored on the spot where they are now embedded." In 1848, Darwin read a paper before the Geological Society[3] upon the Transport of Erratic Boulders, in which he mentions that in 1838 he had observed many boulders of granite (resembling in character that seen *in situ* at the head of the Spey) strewed on Ben Erin, on the western side of Glen Roy, up to the height of 2200 feet above the sea, or 900 feet above the granite *in situ* on Speyside. Similarly Maclaren noticed on Arthur's Seat blocks of sandstone 400 feet above any spot where sandstone now exists *in situ*. Darwin thought that it was by coast-ice that boulders had been transported from a lower to a higher level. Supposing that during a "long course of years," he says, "the land had subsided one or two hundred feet, is it not almost certain that they (the boulders) would have been landed so many feet higher up with respect to the former level, in the same manner as would have happened

[1] "London Phil. Magazine," xxi. 180 (1842).
[2] "Geology of Fife and Lothians," p. 212.
[3] "Geol. Soc. Journal," iv. p. 315. See Plate I.

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with so much drift timber? It is indeed paradoxical thus to speak of the boulders having been carried up, whilst the land has gone down; for, in fact, the boulders are merely kept up by the floating ice at the same level whilst the land sinks." Darwin adduced evidence to show that during the glacial period the land subsided and afterwards was upraised.

In 1855, Darwin considered in an article[1] the power of icebergs in grooving rocks. "Having been induced," he says, "to believe, with many geologists, that certain continuously scored and polished surfaces of rock were due to icebergs and not to glaciers, I have, nevertheless, always felt much difficulty in understanding how long rectilinear scratches, running in a given direction across an *undulatory* surface, could have been thus formed. The paper is written to explain how he thought the difficulty could be removed. Whilst he had formed these views in favour of coast-ice, icebergs, &c., Darwin read, approvingly, the "Great Ice Age," by Professor James Geikie, and honoured its author with letters which appear in his "Prehistoric Europe," and which are by no means antagonistic to Professor Geikie's own theory. One of these letters was written so lately as 1876, and suggests, with regard to the drift near Southampton, "that during the commencement and height of the glacial period great beds of frozen snow accumulated over southern England, and that during the summer, gravel and stones were washed from the higher land over its surface and in superficial channels." Darwin concludes with the words: "When I viewed the country, I could not persuade myself that any flood, however great, could have deposited such coarse gravel over the almost level platforms between the valleys."

But Darwin was destined to be called away from the geological field and to acquire world-wide fame in another. It is not as a geologist but as a naturalist, as a biologist, as the perfecter of the greatest life-theory ever announced, that the name of Darwin will go down to posterity. His famous work on the "Origin of Species," in which he first announced his theory, appeared in 1859, and when I have referred briefly to the geological chapters it contains, I shall bring this address to a conclusion; for Darwin henceforth devoted himself almost entirely to biological studies. His youth saw him an enthusiastic geologist, his old age an equally ardent naturalist. The study of biology is often but a development of the study of geology. "All geological science," said Professor Judd in his presidential address to the Geological Society of London in February 1888, "is based on the principle that the past can only be interpreted by the study of the present; Darwin was the intellectual child of Lyell, and the 'Origin of Species' was the logical outcome of

[1] "Philosophical Magazine," x., 1855, p. 96.

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the 'Principles of Geology.'" And again: "The grand secret of Darwin's success in grappling with the great problem of 'the origin of species' is found in the fact that he was at the same time a geologist and a biologist. The concentration of the later years of his life upon zoological and botanical researches has led many to forget the position occupied by Darwin among geologists. Not only are his geological writings of the highest value for the wealth of accurate observations which they contain, and the important generalisations which they put forward, but in his more purely biological works the value of his geological training and experience are constantly exemplified."

In his "Origin of Species," Darwin candidly admits that the most obvious and gravest objection to his theory that species have descended from species by insensibly fine gradations, is that geology assuredly does not reveal any such finely graduated organic chain. If his theory be true, he asks, why is not every geological formation and every stratum full of intermediate links showing how one species was gradually developed from another? The explanation lies, he believes, in the extreme imperfection of the geological record.

Darwin proceeds to explain this imperfection by reference to

1st. *The lapse of time.*—He remarks that whoever can read Lyell's "Principles of Geology" and not realise how incomprehensibly vast have been the past periods of time may at once close his volume upon the "Origin of Species." He advises the student to examine great piles of superimposed strata, and watch the sea at work grinding down old rocks and making fresh sediment; to wander along lines of sea-coast and mark the process of degradation; or to examine beds of conglomerate many thousand feet in thickness, and then he will perhaps feebly comprehend the lapse of time. But the amount of denudation which the strata have in many places suffered probably offers, in his opinion, the best evidence of the lapse of time. He instances *faults* as affording evidence of, as in Merionethshire, a downthrow of 12,000 feet, yet the surface of the land has been so completely planed down by denudation that there is nothing to show the vast dislocations which have taken place, the pile of rocks on the one or other side of the vault having been smoothly swept away. "The consideration of these facts impresses my mind," he adds, "almost in the same manner as does the vain endeavour to grapple with the idea of eternity."

2nd. *The poorness of our palæontological collections.*—"Now turn to our richest geological museums," he exclaims, "and what a paltry display we behold!" He repeats Edward Forbes' remark that numbers of our fossil species are known and named from single and often broken specimens or from a few

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specimens collected on some one spot. No organism wholly soft can be preserved. Shells and bones will decay and disappear when left on the bottom of the sea, where sediment is not accumulating. He suspects that few of the very many animals which live on the beach betwen high and low water mark are preserved. The imperfection in the geological record mainly results, in his opinion, from the several formations being separated from each other by wide intervals of time. From books or a cursory glance at nature we fancy they are closely consecutive, but we know from observation what wide gaps there are between the superimposed formations, and that during periods absolutely blank and barren in one country great piles of sediment charged with new and peculiar forms of life were being accumulated in another country. He is convinced that all our ancient formations which are rich in fossils have been formed during subsidence. Thus the geological record will almost necessarily be rendered intermittent; indeed each separate formation, like the whole pile of formations in any country, has generally been intermittent in its accumulation.

Again, he reminds us that at the present day, with perfect specimens for examination, two forms can seldom be connected by intermediate varieties and thus proved to be the same species until many specimens have been collected from many places; and in the case of fossil species, this could rarely be effected by palæontologists. He says we shall perhaps best perceive the improbability of our being enabled to connect species by numerous fine intermediate fossil links, by asking ourselves whether, for instance, geologists at some future period will be able to prove that our different breeds of cattle, sheep, horses, and dogs have descended from a single stock or from several aboriginal stocks. This could only be effected by the future geologist discovering in a fossil state numerous intermediate gradations; and such success seems to Darwin improbable in the highest degree. In our geological formations, he thinks, we ought to look for a few links, some more closely, some more distantly related to each other, and we have no right to expect an infinite number of fine transitional forms.

3rd. *On the sudden appearance of whole groups of allied species.*—Darwin admits that if numerous species belonging to the same genera or families have really started into life all at once, the fact would be fatal to the theory of descent with slow modification through natural selection. But he thinks we continually overrate the perfection of the geological record, and falsely infer that, because certain genera or families have not been found beneath a certain stage, they did not exist before that stage.

4th. *On the sudden appearance of groups of allied species in*

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the lowest known fossiliferous strata.—This is a much graver difficulty, in his opinion. If Darwin's theory be true, it is indisputable that before the lowest Silurian stratum was deposited, long periods elapsed, as long as, or probably far longer than, the whole interval from the Silurian age to the present day; and that during these vast, yet quite unknown, periods of time, the world swarmed with living creatures. To the question, Why we do not find records of these vast primordial periods, Darwin admits he can give no satisfactory answer. Yet whilst inexplicable at present, the question may hereafter receive some explanation. Darwin points out that from the nature of the organic remains large islands or tracts of land (whence the sediment which formed the rocks of the various formations was derived) seem to have occurred in the neighbourhood of Europe and North America; but we do not know what was the state of things in the intervals between the successive formations, whether Europe and the United States existed as dry land or were submerged.

Looking at the difficulties caused by the imperfection of the geological record, Darwin considers that we possess the last volume only of that record, relating only to two or three countries. Of this volume only here and there a short chapter has been preserved, and of each page only here and there a few lines. Each word of the slowly-changing language in which the history is supposed to be written being more or less different in the interrupted succession of chapters, may represent the apparently abruptly changed forms of life contained in our consecutive but widely separated formations. On this view, the difficulties above discussed are, in his opinion, greatly diminished, or even disappear.

In the next chapter Darwin discusses the geological succession of organic beings, and arrives at the conclusion that all the leading facts in palæontology simply follow on the theory of descent with modification through natural selection. The extinction of old forms is the almost inevitable consequence of the production of new forms. When a group has once wholly disappeared, it does not reappear, for the link of generation has been broken. We can understand, he says, how it is that all the forms of life, ancient and recent, make together one grand system, for all are connected by generation. "If, then," he concludes, "the geological record be as imperfect as I believe it to be, and it may at least be asserted that the record cannot be proved to be much more perfect, the main objections to the theory of natural selection are greatly diminished or disappear. On the other hand, all the chief laws of palæontology plainly proclaim, as it seems to me, that species have been produced by ordinary generation, old forms having been supplanted by new

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and improved forms of life, produced by the laws of variation still acting round us, and preserved by natural selection."

In a subsequent chapter, Darwin explains how the glacial period to which, he says, "Agassiz and others called vivid attention," affords a simple explanation of the identity of many plants and animals on mountain summits separated from each other by hundreds of miles of lowlands. He says it is perfectly evident that within a very recent geological period Central Europe and North America suffered under an Arctic climate. "The ruins of a house burned by fire do not," in his opinion, "tell their tale more plainly than do the mountains of Scotland and Wales with their scored flanks, polished surfaces, and perched boulders, of the icy streams with which their valleys were lately filled. So greatly has the climate of Europe changed, that in Northern Italy gigantic moraines, left by old glaciers, are now clothed by the vine and maize. Throughout a large part of the United States, erratic boulders and rocks scored by drifted icebergs and coast-ice plainly reveal a former cold period."

It will be observed from this passage that whilst Darwin associated "icy streams" (glaciers), "icebergs," and "coast-ice," with the glacial period of Agassiz, he did not, like Agassiz, assert the existence of an ice-cap, or vast moving field of ice many thousand feet thick. At the same time, he says, "We have good evidence in almost every case that the (glacial) epoch was included within the latest geological period. We have also excellent evidence that it endured for an enormous time, as measured by years, at each point." In fact he considers that during at least a part of the glacial period the cold was actually simultaneous throughout the world. Thus a universal Alpine flora flourished, and to this day on the lofty mountains of equatorial America a host of peculiar species belonging to European genera occur. On the mountains of the Cape of Good Hope some few representative European forms are found, whilst on the Himalayas and the heights of Ceylon, and on the volcanic cones of Java, many plants occur representing plants of Europe not found in the intervening hot lowlands.

I have now dwelt at some length upon Darwin's geological work. I admit that it does not compare in amount or in value with his biological work, and that it was his original researches in natural history that gave him his world-wide fame. Still, in geology as in natural history he occupies a proud position. He stands there in our geological Walhalla as one of the pioneers of geology who, taking the burning torch from the hands of Lyell, carried it down faithfully to our own day. He exhibited in his geological as in his natural history researches, the same indefatigable industry, the same keen-eyed observation, the

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same constant love of truth that were the leading characteristics of his mind and life. When he made a mistake he at once admitted it. Witness his abandonment of his theory to account for the Parallel Roads of Glen Roy. When a new theory was launched, he was not prejudiced against it because it was a new theory, for he knew too much of the riddles of Nature to think that man would decipher them until many and many a theory had been adopted and discarded. In all things he exhibited a broad-mindedness, a modesty, a patience, which make him personally one of the most admirable men of science that ever lived; and it will be to all those who tell the story of his lif, as it has certainly been to me, a labour of love to dwell upon the high personal character of Darwin: there is no need for anyone to extol his peerless intellectual position.

DARWIN'S GEOLOGICAL WRITINGS.

(Selected and arranged from the Appendix to Darwin's Life, vol. iii. p. 362.) Books have * prefixed.

1. *General.*

Geological Notes made on board the *Beagle*. Geological Society's Proceedings, ii. 1838, pp. 210-212. (Incorrectly described as by F. Darwin.)

* Journal of Researches on board the *Beagle*, 2nd edition, 1845. (In the original narrative Darwin's Journal was vol. iii., published 1839.)

* Geological Observations on South America (being third part of Geology of *Beagle* Voyage). 1846.

* Origin of Species, containing Geological chapters. 1859.

2. *Coral Reefs.*

Areas (Coral) of Elevation and Subsidence in Pacific. Geological Society's Proceedings, ii. 1838, pp. 552-4.

* Structure and Distribution of Coral Reefs (being first part of Geology of *Beagle* Voyage). 1842.

Letter on Coral Islands to Charles Maclaren, Edinburgh. Edinburgh New Phil. Journal, xxxiv. 1843, pp. 47-50.

* Structure and Distribution of Coral Reefs, 2nd edition, 1874.

3. *Volcanic Phenomena.*

Volcanic Phenomena. Geological Society's Proceedings, ii. 1838, pp. 654-60; Geological Society's Transactions, v. 1840, pp. 601-632.

* Geological Observations on Volcanic Islands visited by *Beagle* (being second part of Geology of *Beagle* Voyage.) 1844.

Volcanic Rocks and Glaciers. Proceedings Royal Society, Edinburgh, ii. 1851, pp. 17-18.

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4. *Palæontology.*

Deposits containing extinct Mammalia. Geological Society's Proceedings, ii. 1838, pp. 542-4.

* Monograph of Fossil Lepadidæ. Palæontographical Society. 1851.

* Monograph of Fossil Balanidæ. Palæontographical Society, 1854.

5. *Formation of Mould.*

Formation of Mould. Geological Society's Proceedings, ii. 1838, pp. 574-576; Geological Society's Transactions, v. 1840, pp. 505-510.

* Formation of Vegetable Mould. 1881.

6. *Stratigraphy.*

Saliferous Deposits in Patagonia. Geological Society's Journal, ii. part ii., 1838, pp. 127-8.

Sandstone off Pernambuco. Phil. Mag., xix. 1841, pp. 257-60.

Geology of Falkland Islands. Geological Society's Journal, ii. 1846, pp. 267-274.

Pampean Formation, Buenos Ayres. Geological Society's Journal, xix. 1863, pp. 68-71.

7. *Elevation.*

Proofs of Elevation of Coast of Chili. Geological Society's Proceedings, ii. 1838, pp. 446-9.

Areas (Coral) of Elevation and Subsidence in Pacific. Geological Society's Proceedings, ii. 1838, pp. 552-4.

Parallel Roads of Glen Roy. Phil. Transactions, 1839, pp. 39-82.

8. *Glaciation.*

Rock seen on Iceberg. Geographical Society's Journal, ix. 1839, pp. 528-9.

Erratic Boulders of South America. Geological Society's Proceedings, iii. 1842, pp. 425-430; Geological Society's Transactions, vi. 1842, pp. 415-432.

Ancient Glaciers of Wales. London Phil. Mag., xxi. p. 180, 1842.

Erratic Boulders' transportal. Geological Society's Journal, iv. 1848, pp. 315-323.

Volcanic Rocks and Glaciers. Proceedings Royal Society, Edinburgh, ii. 1851, pp. 17-18.

Icebergs' power of grooving. Phil. Mag., x. 1855, pp. 96-8.

Letter (dated 1876) on Drift near Southampton in Professor James Geikie's "Prehistoric Europe."

9. *Dust.*

Fine Dust in Atlantic. Geological Society's Journal, ii. 1846, pp. 26-30.

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II.—*The Classification, Determination, Distribution, Origin, and Evolution of the Normal Micas.* By ALEXANDER JOHNSTONE, F.G.S. (Edin., Lond., Paris).

(Read 20th December 1888.)

THE minerals of the mica family proper are especially distinguished by their one very perfect basal cleavage, which is developed to a degree not known in any other mineral group. This cleavage affords remarkably thin laminæ, each plate of which is flexible and usually elastic, and exhibits a lustre that is generally splendid in degree and metalloidal to pearly in kind. Although a few fairly complete crystals have been found, the micas, as a group, cannot be said to crystallise in any one crystallographic system.

The chemical composition of the various members of the family also differs very considerably. Speaking in general terms, they may be considered to be complex silicates of alumina and the alkalis, potash or soda, with or without lithia, or the alkaline earth, magnesia (and rarely baryta or lime), or a combination of silica with the whole three, viz., alumina, alkali, and alkaline earth. Iron may likewise be looked upon as a constant constituent, which, in some species, attains a position of the first importance.

In the analyses of the six typical varieties of anhydrous mica given below it will be noticed how fairly constant the percentage of alkali is (potash), while quantitatively the other ingredients vary very considerably.

ANALYSES OF TYPICAL ANHYDROUS MICAS.[1]

	Silica, SiO_2.	Alumina, Al_2O_3	Iron Oxides, FeO and Fe_2O_3.	Magnesia, MgO.	Potash, K_2O.	Soda, Na_2O.	Lithia, L_2O.	Fluorine.	Total.
Biotite . . .	40·88	15·21	13·00	22·03	8·84	trace	...	...	99·96
Phlogopite .	39·04	19·99	1·85	30·77	7·98	trace	...	...	99·63
Lepidomelane .	37·68	12·16	40·13	0·36	9·21	trace	...	...	99·53
Muscovite . .	48·56	37·92	3·50	0·25	9·68	trace	...	...	99·91
Soda-Muscovite	47·80	36·64	2·95	0·28	7·84	4·10	...	...	99·61
Lepidolite . .	52·41	26·80	1·99	trace	9·15	trace	4·95	4·10	99 40

The typical hydrous micas have the same general composition as the above, but contain more than 4 per cent. of water.

The specific gravity of the micas usually ranges from about 2·7 to about 3, and their hardness from 2 to 3, according to

[1] Not quite anhydrous, but practically so.

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Moh's scale. The muscovite and hydromuscovite varieties (see below) have usually the lower degree of specific gravity and hardness, and the biotites and hydrobiotites the higher degree.

A New Classification of the Normal Micas.

It is clearly impossible (even if it were desirable) to classify the micas according to crystalline form, and the still common mode of arrangement by means of optical properties into *axial* and *biaxial* groups is also decidedly unsatisfactory. In a paper,[1] read on the 20th February last before the London Geological Society, I gave an account of experiments which tended to prove the general evolutionary relationship of the normal micas. I showed that anhydrous biotite, the common mica of the recent igneous rocks, became, by the long-continued action of natural water containing carbonic acid (or alkaline carbonates), first, hydrated biotite, and then by the gradual loss of magnesia, hydrous muscovite. This latter form by the loss of water becomes the practically anhydrous muscovite, and muscovite exposed to the influence of water passes back into the condition of hydrous muscovite.

Based on those experiments, and on many observations and chemical analyses, I venture to present in a tabular form a new classification of the micas, which at least has the merit of being considerably simpler than any at present in use.

TABULAR CLASSIFICATION OF THE NORMAL MICAS.

DIVISION I.	PASSAGE MICAS.	DIVISION II.
Practically anhydrous micas. Never contain more than 2·5 per cent. of water. Laminæ highly elastic.	Contain from 2·5 to 4 per cent. of water. Have *intermediate* characters	Thoroughly hydrated micas which contain at least 4 per cent. of water. Laminæ flexible and slightly elastic or brittle.
A. Muscovite with its varieties :— 1. Potash or ordinary muscovite (including fuchsite, a variety with a little chromium). 2. Soda-muscovite. 3. Lepidolite (including zinnwaldite and cryophyllite.)	*A*. Muscovite with its varieties.	*A*. Hydromuscovite with its varieties :— 1. Margarodite (including gilbertite, damourite, and sericite, &c. Also Ællacherite, a variety with baryta. 2. Paragonite or hydro-soda-muscovite (including euphyllite). 2. Hydrolepidolite (Cookeite).

[1] "On the Action of Pure Water and of Water saturated with Carbonic Acid Gas on the Minerals of the Mica Family." *Quarterly Journal*, Geological Society of London, May 1889.

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B. Biotite with its varieties :— 1. Ordinary or magnesia-iron biotite (including rubellane and anomite). 2. Phlogopite or magnesia-biotite (including aspidolite). 3. Lepidomelane or iron-biotite (including astrophyllite or iron-titanium biotite).	*B.* Biotite[1] with its varieties.	*B.* Hydrobiotite with its varieties :— 1. Voigtite or hydrous magnesia-iron biotite. Also some micaceous chlorites. 2. Hydrophlogopite (vermiculite and jeffreysite, pyrosclerite, &c. 3. Hydrolepidomelane.

Remarks on the New Classification.

One of the most important features of this classification is that it recognises only four species of mica :—

1. Muscovite.
2. Hydromuscovite.
3. Biotite.
4. Hydrobiotite.

Perhaps it would have been more proper to have further reduced the number to two, viz., muscovite and biotite, by joining 1 and 2 as one species only, and 3 and 4 as another. Certain it is, that the differences in physical properties between these are mainly owing merely to differences in their relative amounts of water. But as these differences are generally readily recognisable, I have thought it desirable, in the meantime at anyrate, to consider them as four distinct species of mica as given above.

Muscovite is usually silver-white or yellow in colour, but is frequently greenish and brownish. Its laminæ are all highly elastic. Its hardness ranges from 2 to 3 and its specific gravity from 2·8 to 3·1. Chemically it is a silicate of alumina, combined with a silicate of potash or soda, or both. Lithia may take the place of part of the alumina or of the alkali metals. The percentage of water in typical muscovite is usually less than 2·5, but it passes over quite gradually into the species hydromuscovite by the increase of water from 2·5 to 5 or 6 per cent. or more. There are three varieties of muscovite :—

1. Potash or common muscovite, which contains about 9 per cent. of potash and not more than about 1·5 per cent. of soda, and usually less.

[1] Including the Haughtonite of Heddle, which is just a form of passage biotite.

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2. Soda-muscovite, which has rarely less than 4 per cent. of soda.

These two varieties, 1 and 2, resemble each other rather closely.

3. Lithia-muscovite or lepidolite, which contains from 2 to 6 per cent. of lithia. Has usually a pale lilac or roseate colour.

Hydromuscovite has the same general composition as muscovite, but is distinctly hydrated, and as a consequence of hydration its laminæ are not so perfectly elastic as those of muscovite, and the lustre is also less splendent, and more pearly in kind. There are also three varieties of this species, each of which corresponds to the same numbered variety under muscovite:—

1. Margarodite or hydrous-potash-muscovite. White, grey, or pale yellow in colour.
2. Paragonite or hydrous-soda-muscovite. Whitish to pale yellow and pale green.
3. Hydrolepidolite or Cookeite. This variety, which is not at all common, is usually very pale lilac to white in colour, but is sometimes yellowish-green, and has a pearly lustre. Its hardness is 2·5, and its specific 2·7. It contains lithia, and about 12 per cent. of water.

Biotite occurs in hexagonal plates or irregularly defined folia or scales. It is usually black in colour or exhibits some dark shade of green, and more rarely brown, red, or dark grey. Its hardness varies from 2·5 to 3, and its specific gravity from 2·74 to 3·13. It is a silicate of alumina, combined with silicate of magnesia or iron, or both, and is practically anhydrous. Its percentage of water as in muscovite is less than 2·5, but like that mineral it passes over quite gradually into hydrobiotite by the increase of water to 4, 5, or 6 per cent., or more. There are likewise three varieties of biotite:—

1. Common biotite, which has usually a dark green, brown, or black colour, and is translucent to opaque. It contains generally about 20 per cent. of magnesia, and about 10 or 12 per cent. of iron oxides.
2. Phlogopite, which is yellowish-brown to brownish-red, and rarely white in colour. It contains much magnesia, and little or almost no iron. This variety of biotite is not very common.
3. Lepidomelane, which is usually raven-black or sometimes leek-green in colour, is translucent to opaque, and has a greenish streak. The folia are usually a little brittle. The hardness is 3, and the specific gravity is 3. It con-

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tains much iron and little or no magnesia. This variety is not very common.

Hydrobiotite is, chemically, practically the same as biotite, except that it is distinctly hydrated, and consequently its laminæ are somewhat talc-like in wanting elasticity, and in having a greasy feel and pearly lustre. There are also three varieties of this species, each of which corresponds to that of the same number under biotite :—

1. Voigtite. This variety has the same composition as common biotite, but is thoroughly hydrated, having 9 to 10 per cent. of water.
2. Hydrophlogopite, which is a thoroughly hydrated phlogopite. Its folia are flexible and inelastic.
3. Hydrolepidomelane is not common.

Between the varieties of muscovite and hydromuscovite, and between those of biotite and hydrobiotite there are varieties showing all stages of gradation, from the practically anhydrous mineral to the perfectly hydrated species. Although it is of course difficult or in some cases impossible to say without a chemical analysis whether a mica belongs to Division I. or to the Passage or Intermediate group, there can very rarely be any hesitation in assigning it either to one of those sections or to Division II.

Determination of the Micas.

I have now to show by means of a table, given below, how the different species and varieties of the normal micas may be most readily distinguished. As preliminary, however, to the tabular method of determination, the following short notes on certain important physical and chemical characters, &c., may be useful.

Notes on Physical Characters.—The biotites in most of cases show dark tints, while the muscovites and hydromuscovites almost invariably exhibit light colours. As the biotites, however, have a great tendency to pass over into the hydromuscovites, through the hydrobiotites, we find a section of them exhibiting, along with the other intermediate physical characters of the passage micas, what may be called intermediate varieties and shades of colour; and as a general rule we observe in tracing the biotites into the muscovites, that as the colour lightens in shade or tint the combined iron and magnesia also lessens in amount.

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The Usual Colours of Thick Pieces of Fresh Micas.

Dark Tints.			Intermediate Tints.	Light Tints.			
Black.	Dark Green.	Brown, Reddish Brown, or Bronzy.	Green, Pale Brown, Red, and Dark Yellow.	Pale Green.	Pale Reddish or Lilac.	Pale Yellow.	Whitish or Grey.
Lepidomelanes. *Biotite* and *Hydrobiotite.*	Lepidomelanes. *Biotite* and *Hydrobiotite.* *Chlorites.*	Lepidomelanes (rare). Biotite and Hydrobiotite. *Phlogopite* and Hydrophlogopite.	*Hydrobiotite.* *Phlogopite* and *Hydrophlogopite.*	Muscovites and Hydromuscovites.	*Lepidolite.*	*Muscovites* and *Hydro-Muscovites.* Phlogopite and *Hydrophlogopite.*	*Muscovites* and *Hydro-Muscovites.* Phlogopite and *Hydrophlogopite.*

Note.—When the species or variety is printed in italics, it means that the colour under which it is placed is its commonest one.

Of the four species of mica, the biotites are generally the hardest and heaviest, and the variety that most constantly maintains the highest average of hardness is lepidomelane, which is also the heaviest. The softest micas are the hydromuscovites.

The following table shows the relative average hardnesses of the typical varieties. The trials were very carefully made in the Geological Laboratory of Edinburgh University on a large number of specimens which were nearly all from different localities.

Table of the Average Hardnesses of the Micas.

Species.	*Variety.*	Mean *Hardness* (according to Moh's scale).
Hydromuscovite	Margarodite (including Sericite, &c.),	1·9
	Paragonite,	2·45
	Hydrolepidolite	2·4
Hydrobiotite	Hydrophlogopite,	2·0
	Voigtite,	2·5
	Hydrolepidomelane,	2·8
Muscovite	Potash-muscovite,	2·35
	Soda-muscovite	2·5
	Lepidolite,	2·5
Biotite	Phlogopite,	2·5
	Common Biotite,	2·7
	Lepidomelane,	3·0

From the above table we learn that the average hardness of the *whole* species of biotite is 2·66; of muscovite, 2·45; of hydrobiotite, 2·43; and of hydro-muscovite, 2·25. Careful experiments

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were also made to determine the average weights or specific gravities of the above with the following results:—The average specific gravity of the *whole* biotite species was found to be 2·96, the muscovite species was 2·90, the hydrobiotite species was 2·86, and the species of hydromuscovite was 2·78. The laminæ of the muscovites are the most perfectly elastic. When we trace their connection with the biotites we find that as the amount of iron and magnesia increases the elasticity diminishes. Increase in amount of combined water also means decrease in degree of elasticity.

Notes on Chemical Characters, &c.

Fusibility.—The biotites and hydrobiotites, with the exception of phlogopite and hydrophlogopite, are generally readily enough fused before the blowpipe. Lepidomelane is easily fused to a black magnetic globule. The muscovite variety, lepidolite, is also fusible without difficulty. Occasionally, but rather rarely, it is found to fuse easily even in the flame of a candle.[1] The two exceptions of biotites named, and the muscovites (except lepidolite) and the hydro-muscovites are with difficulty fusible.

Action of Acids.—Muscovites are practically not decomposed by any of the acids. Lepidomelane is easily decomposed by hot concentrated hydrochloric acid. Hot concentrated sulphuric acid decomposes all the biotites and hydrobiotites, and also, but to a much less extent, the hydromuscovites. Concentrated nitric acid also decomposes the biotites and hydrobiotites.

Fusion.—All micas can be quickly decomposed by heating them on platinum foil with about three or four times their bulk of solid ammonium fluoride,[2] and the presence of magnesia, iron, potash, &c., can be readily detected in the fused residue. For bringing out the iron, however, fusion with potassium nitrate, which also decomposes the micas, is perhaps preferable. By these methods of fusion, biotites can be readily distinguished from muscovites, as follows:—

To the mica residue on plantinum foil, after fusion for about five minutes with ammonium fluoride in a good blowpipe flame, add a small quantity of strong, pure, hydrochloric acid, and boil in a beaker or test-tube for a few minutes. The prepared solution must then be filtered off, and about a third of its bulk of ammonium chloride added to it and afterwards ammonium hydrate, until the whole is properly alkaline. The liquid at this

[1] It is then usually spoken of as cryophyllite.

[2] See an article by the author, "On the Rapid Decomposition of Insoluble Natural and Artificial Silicates," in the *Chemical News* for 28th December 1888. Also a paper, "On the Macroscopic Determination of Igneous Rocks," in vol. v., page 488, of "Trans. Geol. Soc., Edin."

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stage is boiled, and afterwards filtered, to remove from it any precipitate of alumina. When all this has been done, and a clear solution obtained, test it for magnesia by adding a little ammonium phosphate, and shaking the whole mixture of liquids vigorously (in a test-tube) for about a minute. If magnesia is present in any but the very smallest quantity, a white crystalline precipitate will soon separate out from the liquid. If the presence of magnesia by this method is distinctly shown, the mica may safely be referred to the biotite or hydrobiotite species. Should no, or almost no, magnesia precipitate whatever appear, the mica is either lepidomelane, and in that case will be raven black or dark green, and readily fusible alone before the blowpipe, or one of the muscovites or hydromuscovites. The presence of iron can be readily detected in a mica by fusing it with potassium nitrate, moistening the residue with pure nitric acid, and then adding potassium sulphocyanide; the formation of a blood-red coloured mass denotes the presence of iron. To distinguish between the hydrous and anhydrous biotites and muscovites, heat in a small dry glass tube, closed at one end. Water produced on the sides of the tube in conspicuous quantity is evidence that the roasted mica was hydrous.

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Table for the Determination of the Normal Micas.

A. The mica when fused with ammonium fluoride and treated as detailed above, gives a *distinct* magnesia reaction.

1. The mineral yields little or no water when heated in a closed tube.		2. The mineral yields much water when heated in a closed tube.	
Is *readily* decomposed by conc. sulphuric acid, and with little trouble gives a distinct reaction for iron.	Is *slowly* decomposed by conc. sulphuric acid, and gives at most a faint iron reaction.	As for Biotite. It fuses easily to a black magnetic mass.	As for Phlogopite. Folia inelastic. It does not fuse to a magnetic mass.
The mica is Biotite. Colour usually black or dark green.	The mica is Phlogopite. Colour usually reddish or brownish or yellow, rarely white.	The mica is Hydrobiotite (Voigtite). Colour usually leek green, but sometimes dark in shade, or brown or yellow.	The mica is Hydrophlogopite. Colour usually green, yellow, brown, or whitish.

B. The mica gives *no distinct* magnesia reaction after treatment with ammonium fluoride.

1. The mineral yields little or no water when heated in a closed tube.				2. The mineral yields much water when heated in a closed tube.			
Fuses easily to a black magnetic globule. It yields a bottle green glass with borax when heated in the reducing flame BB. It is readily decomposed by conc. hydrochloric acid.	Heated BB with bisulphate of potash, it colours the outer flame purple red. Colour is pale.	Residue after fusion with ammonium fluoride gives at once a very *distinct* golden yellow sodium flame and spectrum.	Residue after fusion with ammonium fluoride gives a distinct pinkish violet flame when looked at through blue glass and potassium spectrum, but no immediate and distinct sodium flame.	As for Lepidomelane.	As for Lepidolite, but the colour is usually paler.	As for Soda Muscovite.	As for Potash Muscovite.
The mica is Lepidomelane. Colour usually black, folia rather brittle.	The mica is Lepidolite. Colour always pale, usually lilac or red.	The mica is Soda-Muscovite. Colour usually white or pale yellow or green.	The mica is Potash or Common Muscovite. Colour usually white, pale yellow, or green.	The mica is Hydrolepidomelane. Colour usually black, dark green, or brown.	The mica is Hydrolepidolite (Cookeite). Colour usually pale lilac to white.	The mica is Paragonite. Colour usually whitish yellow or pale green.	The mica is Margarodite. Colour usually whitish yellow or pale green.

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The Distribution of the Micas.

The geological area of biotite is far more extensive than that of muscovite or any of the other varieties of mica. It occurs largely in all igneous and schistose rocks, but is most abundantly developed in the newer volcanic and plutonic masses. Hydrobiotite has the same general distribution as biotite. Muscovite and hydromuscovite are most abundant in the ancient igneous rocks and crystalline schists, and they are rather rare in the newer igneous rocks. Phlogopite is chiefly met with in certain crystalline schists, and in lenticular masses of crystalline limestone intercalated in these. Hydrophlogopites and hydrobiotite are common ingredients of schists. The lepidomelanes are found in granites and schists and related rocks.

The most abundant and the only very important rock-forming micas are :—

1. Biotite and the Hydrobiotites (except Hydrolepidomelane).
2. Muscovites and Hydromuscovites.

These therefore are the only varieties that it will be necessary to take account of in the following briefly described theory of the origin of the micas.

Theory of the Origin of the Normal Micas.

Seeing that all, or almost all, the micas of the recently formed igneous rocks are of the nature of biotite, which is therefore a product of igneous fusion, and that the micas of the older rocks are referable to the species biotite, hydrobiotite, muscovite, and hydromuscovite, we may safely consider the first named as the original mica, and all the others as being varieties generally derived from it. The experiments which I have already quoted in the first portion of this paper show how the agencies of natural waters, &c., and time, are all that is necessary to bring about the various changes in chemical and physical characters essential to the creation of those other varieties of mica. It is not, I think, needful to describe further the processes of the evolution of the pale tinted species, as the experiments I have referred to and the following diagram show clearly enough the manner in which I believe the various changes must have taken place.

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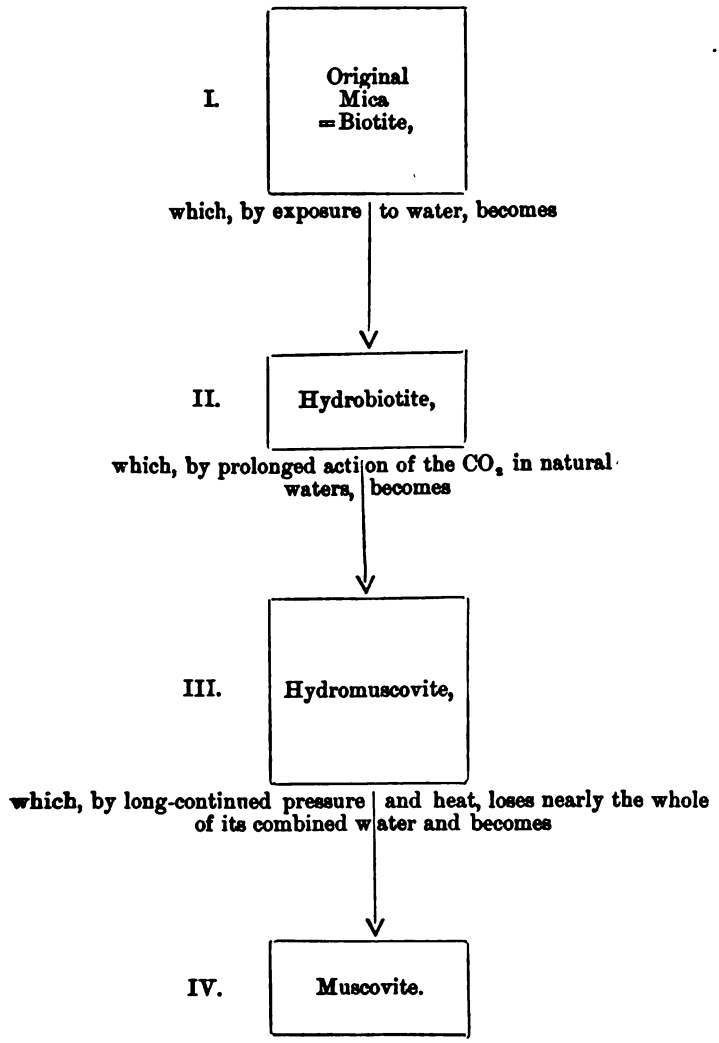
Diagram of the Evolution of the Micas.


I.
Original Mica = Biotite,
which, by exposure to water, becomes
II.
Hydrobiotite,
which, by prolonged action of the CO_2 in natural waters, becomes
III.
Hydromuscovite,
which, by long-continued pressure and heat, loses nearly the whole of its combined water and becomes
IV.
Muscovite.

Note.—The last, by exposure to natural water, can again become hydromuscovite, and then in the same way as III. be reconverted into muscovite; hydrobiotite can also go back again into the condition of biotite.

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III.—*Note on supposed High-level Shell Beds in Easter Ross.*

By HUGH MILLER, F.R.S.E., of H.M. Geological Survey.

(Read 17th January 1889.)

THE statements to which this note bears reference have been published by Mr D. Cameron, of Daviot, in two short papers printed in abstract at pp. 330-31 of the Society's Transactions for 1886, and entitled respectively "Geological Observations in Easter Ross, &c.," and "The Geology of Fearn and Tarbat." Having ascertained from the author of these papers the exact localities of the supposed shell-beds, the writer of this note visited them in the course of his official survey of the district in November last, and he found with regret that the shells, described in one case as Arctic in character are nothing more than the debris of kitchen-midden heaps which are to be assigned to a recent and wholly artificial origin.

The deposit at Cadboll, in the parish of Fearn, stated as 124 feet above present sea-level, is to be seen near the edge of the cliff above the shore of the Moray Firth, near an old quarry of yellow sandstone above a footway which descends upon the beach. It consists of a scattering of shells of the common mussel and other edible species, above ordinary dark soil, with a subsoil of red boulder clay.

The deposit at the fishing village of Portmahomack, in the parish of Tarbat, described as 84 feet above sea-level, is a heap of mussels and limpets thrown out upon a surface of the blown sand which in quite recent times, if tradition is to be trusted, has spread over the neighbourhood of the village. A little section has been scraped out by the school children close beside the new Board School.

A third locality, at the fishing village of Balintore, was visited by the present writer in 1885. The deposit, which he failed to note, is probably of the same artificial character as the other two.[1] It is described as at the level of the fifty-feet beach, which has not as yet yielded shells *in situ* anywhere in Easter Ross.

These corrections of statements which have been made in the Transactions, are rendered necessary by enquiries which have been addressed to the author upon the subject, and are made with much reluctance.

[1] This he has since ascertained to be the case. It consists of a thin layer of mussel shells in blown sand.

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IV.—*On the Succession of the Lower Carboniferous Series to the West of Edinburgh, with special reference to the District around Cramond.* By JOHN HENDERSON.

(Read 21st March 1889.)

IN a former paper on the lower carboniferous rocks of the district, read before this Society, I showed that the beds were bent into two anticlinal folds running north and south. The eastern anticline passes from the shore at Leith southward through St Andrew Square on to the foot of Blackford Hill, while the western anticline passes from the shore at Granton quarry through the south end of Corstorphine Hill on to Wood Hall, near Juniper Green, on the Water of Leith. I sought to show also that the syncline between these two arches was at its northern end occupied by the Wardie shales, while a much higher set of rocks covered these shales at the southern end of the syncline, namely, the sandstones of Redhall and Hailes, with the shales which overlie them. I also showed that these lower carboniferous rocks were cut through by a great fault running south-west and north-east, passing from the north-west face of Craiglockhart Hill to the north side of Edinburgh Castle, and from thence eastwards to the north end of Arthur Seat. This fault is well exposed in the Suburban Railway cutting at Meggetland, where beds of the Granton sandstone group can be seen lying nearly vertically against the red sandstones that form the base of the lower carboniferous series. On tracing this fault south-westwards it seems to skirt the south side of the Water of Leith above Colinton, and crosses that stream somewhere in the neighbourhood of Currie, whence it runs on to the north side of Dalmahoy Craig.

To trace an ascending series of the lower carboniferous rocks in the neighbourhood of Edinburgh we require to begin near their base at the northern foot of Blackford Hill, and going north-eastward in the direction of Arthur Seat we pass over, in ascending order, the red rocks forming the lowest division of the lower carboniferous or calciferous sandstone series. The highest members of this division exposed in the district are the sedimentary beds and contemporaneous traps of Arthur Seat and Calton Hill, and a break, caused by the great fault just referred to, seems to occur between this division and the next above it. The next beds we can take up in ascending order are the beds that form the top of the anticline in the neighbourhood of St Andrew Square. The beds here begin to take a westerly dip,

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and this dip to the west continues on to the Dean Bridge and Water of Leith, where we get as high as the base of the Wardie shales. The strata which underlie the Wardie shales and extend back to St Andrew Square, and consist of alternating beds of sandstones and shales, I term The Granton Sandstone Group. I should have been inclined to have placed this section of rocks and all the beds I have to describe in this paper in one group, but their classification into separate divisions was the work of the Geological Survey, and although the Survey had rather mixed these divisions in their description of the district, I have retained them, as there is at least a local advantage in subdividing the series where it can be done with certainty. Following the strike of the Wardie shales to the south we again find them exposed in the Suburban Railway cutting north of the Canal still dipping west, and from this point we can trace an ascending series westward up through the Wardie shales through the sandstones and shales of Colinton and Slateford up to the sandstones and overlying shales of Redhall Quarry. Here this ascending series ends, since these beds occupy the centre of the synclinal axis, and the next beds met with going west are the sandstones and shales of Hailes Quarry, dipping to the east. Very few sections are exposed from this point westwards, so that to carry these sections further in this direction we require to go a mile to the south, where, on the Water of Leith at Colinton West Mill, the rocks are well exposed in the bed of the river. Here we find the south end of the synclinal axis. The beds first dip west, then north-west, then north, north-east, and east. This easterly dip continues for nearly a mile up the stream, when, at Woodhall, near Juniper Green, we again come upon the base of the Wardie shales arching over, and again resuming the westerly dip, and forming the southern end of the west anticline. Further west the upper portion of these shales forms a series of small synclines and anticlines, then the beds take a decided dip to the west, but the series never rises to the height of the Redhall beds again, but is cut off by the great fault that crosses the Water of Leith in this neighbourhood. West from Kinleith Mill members of the red group are only to be seen in the bed of the river.

Northwards from Currie and Juniper Green very little rock is exposed till Corstorphine Hill is reached, but on the north-east side of that eminence many evidences of the western anticline are to be found. At the quarries of Craigleith, Blackhall, and Ravelston the rocks dip to the east. At Fountainhead and Craigcrook Quarries they are dipping southwards, and on the eastern face of Corstorphine Hill sandstones and shales are exposed dipping west. But it is on the shore between Granton and Cramond that the best sections for tracing the

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upward succession of this—the middle—portion of the lower carboniferous series, are to be met with. Taking as a starting point the base of the Wardie shale group situated on the west side of the west breakwater at Granton, and going westward, we find these shales dipping east at angles of 15° to 40°. They are underlain by the thick-bedded sandstones of the General's Rocks and Caroline Park, which have the same easterly dip, and are the equivalents of the sandstones of Craigleith Quarry. Beneath them comes a series of sandstones and shales which can be traced westward to Granton Quarry, all having the same easterly dip, varying from 20° to 30°. The distance from the outcrop of the base of the Wardie shales to Granton Quarry is about 1000 yards, and taking the average dip at 25° this would give a vertical thickness of 1350 feet of sandstones and shales belonging to the Granton sandstone group in this section. West from Granton Quarry no rock is exposed for a distance of about 300 yards, when beds of sandstone and thin sandy shales are met with, dipping at a low angle to the west, and from there on to Muirhouse, about half a mile west of Granton Quarry, thin bedded sandstones and shales are exposed, dipping in all directions at very low angles. West from Muirhouse the beds begin to take a steady dip to the west, and continue so for 200 or 300 yards, dipping at angles of from 12° to 20°. Further west from this no rock is exposed on the beach for about three quarters of a mile, but out in the sea in front of the beach, between Granton Quarry and Muirhouse, beds of sandstone can be seen arching round with a north and north-west dip. These sandstone beds seem to take their rise from beds that run into the sea with an easterly dip a little to the east of Granton Quarry, and consequently overlie the sandstones of that quarry. They arch round to the west, and approach the shore with a north-west dip in front of Muirhouse. About a quarter of a mile west from Muirhouse, two or three hundred yards out on the sands, thick bedded sandstone is again seen, but it is so rounded by the action of the waves that I could not make out the dip and strike. It is exposed for about 30 or 40 yards each way, and is, no doubt, one of the thick courses of sandstone belonging to the Granton series which strike inland on this, the western, side of the anticline. About a quarter of a mile farther west, in a field behind Broomfield Cottage, a few yards from the beach, a grey felspathic rock has been quarried. It is termed by the Survey a contemporaneous felspathic ash. Its relation to the carboniferous rocks cannot be made out, as only a small portion has been exposed by quarrying. Between 300 and 400 yards west from this point beds of sandstone are again met with dipping southwest at 30°,

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and extending for about 60 yards. These are succeeded by other beds about 20 yards in extent, dipping west at 55°, the whole showing a vertical thickness of about 130 feet. These sandstone beds, I consider, are the equivalents of the Craigleith Quarry sandstones which lie at the top of the Granton group, for reasons that I shall now explain. In the first place, if we consider the distance from this point to the centre of the anticline, and the dip of the beds, we find that a great thickness of rock with a westerly dip must intervene between these two places. The distance from these sandstone beds to the centre of the anticline is about one mile, and the dip from 12° to 55°. Taking the average at 30°, this would give a vertical thickness of 2500 feet, which is much more than my estimate of the thickness of the same beds on the east side of the anticline. For some distance, however, on the west side of the anticline the beds have no decided westerly dip, but taking the distance from Muirhouse, where the dip becomes steadily westerly—a distance of nearly three quarters of a mile—we should get about the same thickness as the Granton beds on the east side of the anticline. Another reason I have for considering these sandstone beds as marking the top of the Granton group is that the Wardie shales, which lie under the greenstone of Corstorphine, with a westerly dip, would, if continued northwards along their line of strike, pass into the sea about this place, a circumstance shown on the maps accompanying my former papers on these lower carboniferous rocks. Taking this then again as our starting point, and continuing the sections west, we ought to find the Wardie shales coming on immediately above these sandstones, but, unfortunately, no rock appears for about 80 yards, when a bluish whin is met with about 30 yards in extent, and about 20 yards farther on we come upon thin bedded sandstones dipping west at 50°. Now, I consider the space lying between these two sandstones where no sedimentary beds are seen, a distance of about 130 yards including the trap, to be occupied by the Wardie shales, and it is a very common feature of this part of the coast to find that the shales and other soft rocks have been scooped out into little bays and covered by the sands and gravels of the beach, while the harder sandstones and traps stand up as ridges running out into the sea. West from this, for upwards of 500 yards, sandstones and shales are exposed here and there, all having a westerly dip at angles of from 40° to 60°. Then comes a set of thick and thin bedded sandstones, 80 yards in extent. These I consider the equivalents of the Redhall and Hailes beds, and my reasons for doing so are, first, the distance between these sandstone beds and what I consider the probable position of Wardie shales

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is upwards of 500 yards, and the average dip about 50°. This would give upwards of 1000 feet of vertical thickness of beds lying between the Wardie shales and these sandstones, which is not far off the thickness of the beds that lie between the Wardie shales and the Redhall sandstones in the Craiglockhart, Colinton, and Slateford districts. Again this sandstone shows in many places thin straight lines of lamination, a feature remarkable on the weathered faces of the Hailes Quarry sandstones. This feature is also observable in the sandstone beds of an old quarry in the Barnton grounds, lying to the west of the greenstone of Corstorphine Hill. The beds in this quarry dip to the west, and would, if continued northward along their line of strike, reach the shore about the spot where these sandstones occur. If my opinion is correct, we have now reached as high a place in the series as it is possible to reach in the southern sections, namely, the horizon of the Redhall and Hailes sandstones, and all the succeeding beds I have to notice belong to a higher part of the series. These sandstones have a vertical thickness of about 160 feet, and about 100 yards further west another bed of trap is met with, 50 yards in extent. Then there are sandstones and shales for 50 yards, followed again by trap 30 yards wide. Further west for about 200 yards no rocks are exposed, when, at the mouth of the Almond, sandstone beds are again met with, dipping west at angles of from 30° to 50°. These sandstone beds, on which the village of Cramond is built, are overlain by beds of trap 100 yards in width, which occupy the bed of the river from one side to the other, and form the cliff on the west side, on which the boatman's house is built. From here west for about 200 yards no exposure of rock occurs, when another bed of trap is met with. Then comes another space of 300 yards or so where no rock is seen, which brings us to the sandstone cliff on the estate of Lord Rosebery, known as the "Eagle Rock," but the beds that are expected to lie between this and the mouth of the Almond will be noticed when I describe the sections exposed up that river. The Eagle Rock, which takes its name from what is supposed to be the figure of an eagle carved on its eastern face by some of the Romans when they occupied this district, somewhere about eighteen hundred years ago, is a thick-bedded sandstone, strongly marked with lines of oblique lamination, dipping west at about 12°. This is followed by a set of thick and thin bedded sandstones, and brown and bluish shales, dipping west-south-west, at from 12° to 20°. These continue for about 400 yards, where a great mass of trap is met with resting on black shale, the trap having the same dip and strike as the sedimentary beds. This is the western limit to which I carry

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my present paper. In the set of sandstones and shales just mentioned, a little above the sandstone of the Eagle Rock, in a thin bed of brown micaceous shale, fragments of scorpions are pretty abundant; but the bed is difficult to get at now, owing to the sand and gravel drifting in upon it.

Returning again to the mouth of the Almond, and going up that river, we find a number of very interesting sections exposed. From the mouth up to the first damhead, a distance of a quarter of a mile, the river runs along a bed, or a series of beds, of trap of varying character and hardness. This trap seems to have been intruded among beds of black shale, and in several places the shale can be seen enclosed between beds of the trap, hardened and baked white by contact with it when in a molten condition. This trap in its middle portion is so soft and friable, that it might be dug out with a spade, while at the top and bottom the rock is so hard that it can scarcely be broken with the hammer. The beds are about 100 yards wide, and run nearly due north and south, with a dip to the west. They are overlain by about 12 feet of black shale, which seems to run parallel with the trap down to the mouth of the river. It used to supply the masons and joiners of Edinburgh and the neighbourhood with black coal, as it is called, for marking their work before the present age of large and cheap pencils. Above this shale, at the damhead, lies a bed of felspathic trap, also dipping west. It is about 10 feet thick here, but seems to thicken out towards the north, for in a wood at the shore it can be traced northerly to the extent of 50 yards in width. Above this, at the damhead, comes another bed of black shale, the thickness of which cannot be made out. Still higher up, the river takes a bend to the south-west, and the trap beds are either lost on the south-east bank, or are cut off by a fault that occurs here, for the next beds met with are a set of coarse red and grey sandstones dipping north-east at about 20°. These sandstone beds can be traced up the river for several hundred yards, increasing in dip till within a few feet of the old quarry opposite the old Fairafar Mill, where beds of black shale are exposed standing nearly on end against the horizontal bedded sandstones of the quarry. The shale here is interesting, from the fact that it is a paraffin shale, and is the lowest oil shale, as far as I am aware, of any considerable thickness that has been met with in the lower carboniferous rocks of the district. A thickness of 6 or 7 feet of it is exposed here, but neither top nor bottom can be seen, and it appears to dip at a very high angle to the north-east, and strike south-eastwards, as beds of oil shale crop out on the opposite side of the river in that direction. In almost immediate contact with these nearly vertical shales lie the

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sandstones of the quarry, which being almost horizontal, indicate a fault here, running north-north-west and south-south-east. The sandstones of the quarry are exposed in fine sections on both sides of the river, between Fairafar Mill and the old paper mill. The river has cut down through the sandstone beds to a depth of from 30 to 40 feet, showing a vertical cliff on each side. The bedding is nearly horizontal, but where the dip can be seen it varies so much that it is not easy to determine which is its true direction. The position of this sandstone owing to the faults cannot be well defined, but it lies in the line of strike, and in some respect resembles the sandstone of the Eagle Rock, and is in all likelihood a continuation inland of that sandstone. Above these sandstones beds of sandstone dipping south-west are exposed on the west side of the river, and opposite the old paper mill another bed of oil shale occurs, also dipping south-west. This bed is much crumpled and broken, and closely resembles the one opposite Fairafar Mill. Neither can its dimensions be precisely determined, as a very small section of it is exposed, showing a thickness of a few feet only. Further up the river the beds seem to dip various ways till near the Old Spade Mill they take a steady south-south-west dip, and closely resemble in character the thin bedded sandstones and brown sandy shales that lie above the sandstone of the Eagle Rock (the last beds on the coast section.) Further up the river no rock is met with till about a quarter of a mile above Cramond Bridge, where beds of shale several hundred feet in thickness are exposed, dipping west. These shale beds contain no oil shale as far as I could make out. They dip under the great mass of greenstone of Craigiehall, which is a continuation, according to the Survey, of the last bed of trap mentioned in the coast section. These sections that I have been describing lying above the representatives of the Redhall and Hailes group carry us through a vertical thickness of over 1000 feet, and we now meet for the first time in the upward succession beds of oil shale of any considerable thickness. How far these lie beneath the Burdiehouse group I cannot yet say, but I think we have got within a measurable distance of the Queensferry beds, and I hope to give a paper soon again on the beds that lie between these sections and the Queensferry or Burdiehouse limestone. One of the most striking features of the lower carboniferous strata of our district is the great thickness of the rocks included. In the section along the coast that I have described, extending from Granton Quarry to the westmost greenstone, about half a mile west of the mouth of the Almond, we find representatives of all the groups in the middle portion of the lower carboniferous series, viz., the Granton sandstones, Wardie shales, sandstones and shales of

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Colinton and Redhall, and the beds that lie between this last and the Queensferry limestone. From Muirhouse, where the beds begin to take a steady westerly dip, to the westmost point of our section, is a distance of two miles, and if we take the average dip at 30°, which is not too high an estimate, we should get a vertical thickness of over 5000 feet, or one mile, in this coast section. In this there are five beds of trap, with an aggregate thickness of 400 or 500 feet. This does not include the felspathic rock at Broomfield Cottage. These trap beds appear to dip conformably with the strata, and have the same direction of strike as the sedimentary beds among which they are intruded, and they have each distinctive characters from one another. As far as I could make out there seems to be very little displacement or repetitions of the strata through faults in the coast sections, although there are faults in the sections up the river Almond, the extent and nature of which I have not yet been able to determine, but I hope to have more to say about them in connection with the higher beds to the west in a future paper.

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V.—*An Old Man and Woman; or, Human Bones in a Scrobicularia Bed at Newton Abbot, Devonshire.* By WILLIAM PENGELLY, F.R.S., F.G.S., &c.

(Read 18th April 1889.)

On 7th September 1885, while travelling in Scotland, I received a letter from Messrs Watts, Blake & Bearne, clay merchants, Newton Abbot, Devon (hereinafter called "Newton"), stating that during an excavation, then in progress, for the reception of a new gas-holder at the Newton Gas Works, a human skull and other bones had been found which were probably worth attention; that an iron key had been found in the same excavation; and that, at their suggestion, Mr Clarke, manager of the works, had put aside the finds just mentioned, in order that I might examine them if disposed to do so.

On going to Newton on 27th September 1885, I found the excavation completed, and the new gas-holder in its place, but not quite finished. Mr Clarke not only received me most kindly, but presented me with all the objects which had been put aside, as well as the memoranda he had made respecting them, and added to my obligations by the clear answers he gave to all my questions.

The excavation is in the "Marshes," west-north-westerly from Newton Railway Station, and about a quarter of a mile from it as the crow flies. It is on the right shore of the tidal estuary of the river Teign, from the nearest point of which it is about 1100 feet distant. Mr James Barry, river surveyor, kindly informs me that the surface of the ground adjacent to the excavation is 2·14 feet above the equinoctial spring-tide level at Newton.

The deposits passed through in making the pit were, in descending order:—

1.	Vegetable soil, ...	2 feet.
2.	Fine sandy mud of very dark colour, .	11 „
3.	Gravel, generally well rounded, but containing a few sub-angular stones,	2 „
4.	Light coloured clay (the "pipe-clay" so largely exported from the district), the bottom of which was not reached,	6 „
	Total depth of the pit, . .	21 feet.

The "fine sandy mud"—the second bed—was the only one in which any organic remains or other objects of interest were

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observed. In it, from top to bottom alike, there were shells of *Scrobicularia piperata*, Linn., and *Ostrea edulis*, Linn. The former were so abundant that, in the language of the workmen, there were "hundreds of thousands of 'em," and judging from the number I observed in a large heap of the sandy mud which had not been carted away, they must indeed have been very plentiful. I noticed in this heap several instances of the valves united and closed as when the mollusc was alive. The oysters, though less numerous, were very far from being rare. Of the few I collected, the exterior of one was covered with *Serpulæ*, the outer surface of another was traversed with numerous minute perforations, while a "dead shell" had on its inner surface a few *Serpulæ* and a considerable patch of *Flustra*.

Bones of mammals, I learned, had been tolerably numerous in the scrobicularia bed, but until the human skull and a few bones found with it were dug up, no attention had been paid to them. This find was met with 12 feet below the surface; that is, 10 feet below the top, and 1 foot above the bottom, of the bed. An inspection of the heap of deposit already mentioned enabled me to add to my collection a portion of the horn of a red deer (= *Cervus elaphus*, Linn.), which the workmen assured me had been dug out of the same bed, but they could not state at what depth it occurred.

The only artificial article noticed was the large iron key already mentioned, which is presumably of no great antiquity. It was met with 3 feet below the surface, that is, 1 foot deep in the scrobicularia bed.

I was by no means unprepared for the shells already mentioned, nor do I doubt that their original occupants had lived and died where the shells were found, for it may be safely concluded that the area now under notice is a silted-up portion of the estuary of the Teign, of which it is a part of the present shore. This river, a few years ago, by undermining a portion of its left bank, about a quarter of a mile north-eastward from the pit for the new gas-holder, laid bare a considerable accumulation of shells of scrobicularia and oyster, of which, when at the spot, I took specimens, and also of the deposit in which they lay. Some of the oysters have the minutely perforated exteriors which, as already mentioned, characterise some of those at the gas works.

A consideration of the presence of the shells found in 1885, and of their parasites, as well as of the level they occupied in relation to the existing tidal levels of the district, led me to enquire whether or not they afforded any evidence of a change in the relative level of sea and land in the locality.

The few bones found with the human skull were a femur,

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a scapula, part of a maxilla containing two teeth, and a vertebra; all human except the vertebra, which belonged to some larger form. All the human exuviæ, except the maxilla, have been submitted to Mr J. G. Garson, M.D., of the Royal College of Surgeons, London, and his decision respecting them, confirmed by Mr A. Macalister, M.A., M.D., the Cambridge Professor of Anatomy, to whom also they have been submitted, is briefly as follows :—

The skull is that of a woman, and of what is known as the *Round-Barrow* or *Brachycephalic* type.

The femur has lost its distal extremity, but is otherwise tolerably perfect, and has undergone but little abrasion. When entire it could have been but little, if at all, short of 19 inches long. Its proportions are robust, and the *Linea aspera* is strongly developed. It is undoubtedly the thigh bone of a male, and if the height of a human being can be even approximately calculated from the length of the femur, he must have been a decidedly tall man.

The scapula, also that of the right side of a man, has undergone some damage at parts of its edges, but has suffered little from friction; and, like the femur, is above the ordinary size.

The portion of Maxilla has been submitted to Mr E. B. Pearman, a distinguished dentist at Torquay, who has kindly favoured me with the following statement respecting it:—

"The relic is a fragment of the human superior left maxilla, containing the empty sockets of the central and lateral tooth, a canine firmly embraced by its alveolus, and a first bicuspid with part of its alveolus. The age of the subject must have been about sixty; and from the wearing away of the enamel of the canine and bicuspid, the subject must have done some hard work. The whole of the *pointed* canine is gone, and ground to the dentine, which is highly polished. On first looking at the case, I thought that by the empty sockets of the central and lateral, the teeth had been lost during life; but, on touching with a probe, I found they only contained dust, so the subject certainly died with those teeth in. The curve above the empty sockets, which, with the right superior maxilla, helps to form the floor of the nares or nostrils, is well defined, as is also the palatal bone.

"(Signed) E. B. PEARMAN."

"17*th August* 1886.
"4 PARK PLACE, TORQUAY."

It is obvious from what has been stated, that the bones represent two human individuals, and the two sexes; but, if we may trust the anthropologists, they both belonged to the *Brachy-*

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cephalic race. (See Greenwell and Rollestone in "British Barrows," ed. 1877, p. 654.)

Returning now to the question of levels. The late Mr R. A. C. Godwin-Austin, F.R.S., F.G.S., spoke of "the range of *Scrobicularia piperata* being from low water to four fathoms beneath" ("Quart. Jour. Geol. Soc.," xxii. 5); and the late Mr J. Gwyn Jeffreys, LL.D., F.R.S., stated of the same species: "Habitat: beds of mud and clay at low water mark, and as deep as four fathoms seaward" ("Brit. Conch.," ii. 445-6). The latter author makes the following statement respecting the oyster: "Habitat: 0·45 fathoms" (*Ibid.*, ii. 39).

It is stated in the "Channel Pilot," Part I., "published by order of the Lords of the Admiralty" (ed. 1874, p. 16), that the spring tides at Teignmouth rise 13 feet; and this is in accordance with a communication with which the harbour master has favoured me. Now, remembering that, as previously stated, the top of the scrobicularia bed is now permanently a few inches above the highest spring tide high water, it follows that the top of the bed is upwards of 13 feet above spring tide low water, and the bottom of the said bed is fully 2 feet above spring tide low water. In other words, the top of the bed can at present never, even at spring tides, be quite reached by salt water; and the lowermost 2 feet of the bed, if covered with water at all, can only be covered with perfectly fresh water during several hours twice every day.

If it be assumed that the local tidal phenomena were pretty much the same when the scrobicularia bed was deposited as they are at present, and that *Ostreæ*, *Scrobiculariæ*, and *Serpulæ* —though able to live for short periods in water, having but little salinity—have their normal highest level nowhere above the level of low water, the figures just produced apparently necessitate the conclusion, that in the locality under notice there has been a change in the relative level of land and sea, whereby the land has become relatively higher by at least 13 feet than it was during the deposition of the said bed. If, however, we suppose the base of the bed at the pit was, at the time of its deposition, 4 fathoms below the level of low water —the maximum assigned by naturalists to *Scrobicularia piperata* —the change of relative level must have been fully 26 feet.

In the foregoing speculation it has been tacitly assumed that the scrobicularia bed was never more than 11 feet thick at the area of the pit. It is possible, however, that after the close of its deposition it may have been shorn of some feet of its thickness by denudation before the lodgment of the vegetable soil—the uppermost bed. This, however, could only have the effect of augmenting the change of relatively level.

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Geologists are well aware that near Hope's Nose, Torbay, south-easterly from Newton Gas Works, at a distance of about seven miles as the crow flies, there is a fine example of a raised beach, replete with shells of oyster and such other molluscs as now live in the bay; that its height shows an elevation of little, if at all, less than 30 feet; and that corresponding beaches occur elsewhere in the bay, as well as at frequent intervals westward to the Land's End. It will be seen that this elevation corresponds very closely in amount with the maximum hypothetical elevation of the scrobicularia bed.

It must not be concealed that, so far as I am aware, no *Scrobiculariæ* have been found in any of the raised beaches just mentioned, the materials of which, however, are anything but likely to have formed a suitable habitat for them. I learn from Mr A. R. Hunt, F.G.S., F.L.S., of Torquay, who has devoted much time and attention to the conchology of the Torbay raised beaches, that he has found in them shells of twenty-seven species of molluscs, and that scrobicularia is not among them. Geologists, however, need not be reminded that *Ostrea edulis* and *Scrobicularia piperata* were members of the British molluscan fauna as early at least as the era of the crag deposits of East Anglia.

Geologists familiar with the coasts of East Devon and West Dorset are aware that there is no trace of a raised beach along the entire coast between Hope's Nose and Portland Bill; and, knowing also that the cliffs throughout this interval consist of comparatively perishable rocks, they conclude that in all probability such beaches formerly existed there, but that the cliffs have been wasted by the waves, and the raised beaches have perished with them.

If I have correctly interpreted the Newton phenomena, we have evidence that Devonshire, east of Hope's Nose, shared in the upheaval which is attested by the raised beaches near, and west of, that headland; and we have an intimation that between Torbay and Portland such evidence must be sought, not in the sea cliffs, but in the plains through which the rivers flow. There is reason to believe that evidence of this kind will to some minds be more conclusive than the most striking raised beaches.

With regard to the occurrence of the human bones not more than one foot above the bottom of the bed in which they lay, two hypotheses may be entertained:—

1st. That they were less ancient than the era of the deposition of the bed, and that they sank through the fine sandy mud to the place they occupied.

2nd. That they were coeval with the bed.

The first hypothesis has two aspects:—

(*a.*) That the entire human bodies—flesh and bone—of which

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they are remnants, sank through the deposit. This does not appear to me to be tenable, since the specific gravity of the human body is so very nearly the same as that of water, the pressure of a body on the bottom must be too inconsiderable to enable it to overcome the resistance of even a mass of fine sand. Moreover, this hypothesis would lead us to expect that two complete, or nearly complete, skeletons would have been disinterred by the workmen instead of a very few bones only.

(*b.*) The second aspect is that instead of the entire skeletons, a few naked bones—perhaps simply those now in my possession —were all that were ever lodged on the bed, and that from their greater specific gravity they would have a more decided tendency than entire bodies to sink into the mud. There can be no doubt that this aspect is less untenable than its rival. Nevertheless, even a naked bone would lose very nearly two-thirds of its weight in water, and it is obvious that the form of a scapula is very unfavourable for such sinking as is here contemplated. Moreover, the iron key, which would lose more than one-eighth of its weight in water, sank no farther than 1 foot deep—if it sank at all—in the sandy mud, while the bones sank in it, if at all, to a depth of 10 feet. On the whole I decidedly prefer the second hypothesis, namely, that the bones were coeval with the part of the bed on which they lay. With regard to *Scapulæ*, I remember that in my early sea-faring days it was held that on account of their form they were capable of floating on the surface of the sea, and would thus afford a witch a splendid opportunity for coming aboard. In fact, our skipper never allowed a scapula of a sheep to be thrown overboard until a large hole had been made in it with a marline-spike, so as to prevent its being used as a "witch's boat."

According to my interpretation of the facts, the man and woman represented by the relics under notice were as old as the era of the deposition of the raised beaches of Devonshire, and therefore older than the period of their upheaval; but for this we are by no means unprepared, as the molluscs of the said beaches limit them to a post-glacial age; and the caverns of the neighbouring Torbay district have undoubtedly established for Devonshire man a very early post-glacial, if not, as I believe, a pre-glacial antiquity.

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VI.—*Improvements in the Methods of Determining the Composition of Minerals by Blowpipe Analysis.* By ALEXANDER JOHNSTONE, F.G.S. (Edinburgh, London, and Paris).

(Read 2nd May 1889.)

IT is now beginning to be clearly recognised that mineralogy is not a mere *branch* of chemistry or physics, but is more or less an independent science which requires to be pursued with as much singleness of purpose as any other department of knowledge. As the science of naturally occurring elements and compounds, mineralogy is essentially practical. One of its chief objects is of course the identification of its raw materials or minerals, whether occurring in veins, lodes, or rock masses. When mineralogy was regarded as a department of physics, its minerals were frequently successfully identified by physical methods, some rapid, many slow, but most of them taken alone, decidedly uncertain in their results. Considered as a branch of chemistry, the minerals were generally accurately enough determined by the processes of modern chemical analysis, which however have the great disadvantage, if correct, of being extremely slow. The methods of identification of the modern mineralogist must, I consider, be both rapid and easy. He has no time or inclination to spend over the slow determinations of the multitudinous materials which fall before his hammer. He must either determine all quickly, or one and two slowly, and leave the others unknown, or send them on to a chemical friend to be identified, which is also a highly unsatisfactory proceeding. I hold what I consider the reasonable and proper view that the mineralogist should be able to identify all his own materials without the slightest assistance from either the specialist in chemistry or physics. He should, of course, be acquainted with fundamental chemical and physical methods, but should arrange, modify, and work these in an altogether independent fashion to suit his own special mineralogical requirements. His methods of determination also must be simple, easy and sure; a difficult method is little better than none, as it is almost always certain to be unsafe, no matter how skilfully and carefully it be conducted.

The science and art of blowpipe analysis is the department which gives by far the greatest assistance to the mineralogist. It has been unjustly neglected in the past, at least since Plattner's time, but its position is now improving, and new researches by mineralogists are continually simplifying its methods, and creating new, or changing for the better the mode of applying old time-honoured tests. The day is not far distant, I hope,

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when we shall have rapid and trustworthy tests for every known element, under all possible known natural conditions. When that day does arrive we shall undoubtedly have the analytical chemists coming over to us, and learning from us, and the science of inorganic chemistry itself may then in its turn be considered by the authorities of the world at the time, to be but a handmaiden of its former supposed subordinate mineralogy. The operations of blowpipe analysis are at the present time about ten in number, viz.:—

A. *Heating in the Closed Tube.*
B *Heating in the Open Tube.*
C. *Heating on Charcoal, alone.*
D. *Healing on Charcoal, with flux.*
E. *Heating on Platinum Wire.*
F. *Heating in the Borax Bead.*
G. *Heating in the Microcosmic Salt Bead.*
H. *Heating to produce a Film on Porcelain.*
I. *Heating on Platinum Foil with flux and nitre.*
J. *Heating on Platinum Forceps to determine fusibility.*

I have affixed at the end of this paper tables which show all the fairly decisive, correct, and workable tests known at present, that come in under each of the above operations. I have vigorously eliminated all tests and methods which in my practice I have found to be unsatisfactory.

In connection with operation A. I have been fortunate enough to discover an extremely simple, easy, rapid, and very correct method for the detection of mercury. All substances containing mercury, it is well known, yield when heated in a piece of glass tubing closed at one end, a sublimate which is either metallic or non-metallic in character. Most compounds of mercury are decomposed by heat alone, and so furnish, when subjected to a certain temperature, the former sublimate; but mercur*ous* chloride (calomel) and bromide, and mercur*ic* chloride (corrosive sublimate) and iodide, and to a certain extent the sulphide also (cinnabar), are volatile without decomposition, and accordingly produce sublimates of non-metallic lustre. All compounds of mercury, however, when dry and intimately mixed with three or four times their bulk of fusion mixture (dry anhydrous carbonates of soda and potash) yield, under the influence of heat, metallic mercury, which condenses on the cooler portions of the tube above the assay. When this metallic sublimate is small in amount, or mixed with other matters, it may easily be mistaken for arsenic, and sometimes, though rarely, for antimony. The method which I have introduced decides the question at once. Pour *a single*

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drop of moderately concentrated nitric acid into the tube coated with the metallic sublimate, and immediately afterwards *a drop* of a fairly strong fresh or undecomposed solution of potassium iodide in water, and warm the bottom of the tube *slightly*. The potassium iodide is at once split up by the nitric acid, and the newly liberated iodine acts with energy on any mercury in the sublimate or assay, producing the unique scarlet iodide of mercury on the sides of the tube.[1] The formation of this scarlet iodide is a very good indication of the presence of mercury. In operation B. I have also introduced a new test, which has, I think, likewise the merit of simplicity and accuracy. Antimony and *most* of its compounds give when heated *alone* in the *open tube*, and *all* its compounds when heated with flux, a distinct white sublimate. But native arsenic, arsenical compounds, sulphide of lead, ammonium chloride, &c., also give good white sublimates in the open tube. Whether or not the sublimate is antimony oxide, or contains that body, can be easily ascertained by pouring down the sides of the tubes upon it a drop of ammonium sulphide. If antimony is present, the highly characteristic orange-coloured sulphide of antimony will immediately form. This test can also be applied in operation A. if a black metallic sublimate forms near the assay after heating with flux; but it can in all cases be best used, especially if the quantity of antimony is very small, in the next operations (C. and D.) on charcoal.[2] If any white incrustation or coating forms on charcoal in either of these operations, simply touch it with ammonium sulphide, and the orange sulphide will distinctly form if any antimony is present, especially if the test be applied while the charcoal (which should have a smooth surface) is still in a fairly warm condition.

In operation D. I have been able to confirm the presence of tin, which is usually considered by the ordinary worker to be one of the most difficult of ore metals to detect satisfactorily, and, at the same time, easily and quickly. The beads or scales of white malleable metal supposed to be tin, obtained by heating the powdered mineral with flux,[3] and afterwards grinding and lixiviating the fused residue, are heated on porcelain for a very short time with *two or three* drops of moderately strong hydrochloric acid. After the process of heating, one drop of the acid must be left on the porcelain undried up. A drop of gold chloride solution is then added, and soon, if the metal treated in this way was tin, or an alloy containing tin, the very characteristic "purple of Cassius" distinctly appears.

[1] See *Chemical News*, May 10th, 1889.

[2] Or aluminium plate can be used in place of the charcoal.

[3] Obstinate stanniferous minerals, such as tin pyrites, require to be treated also with cyanide of potassium, and with borax.

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It is well known that by the usual method of performing operation E. only the fusible minerals give the characteristic flame colourations or spectrums. I have been able to obtain these, however, from the most infusible silicate by heating, and so partially decomposing the refractory substance for about five or six minutes with solid ammonium fluoride before applying the test.[1] I thoroughly and repeatedly moisten the platinum wire first with hydrochloric acid, and get what results I can with this residue in the Bunsen flame; and, second, with silver chloride, using it in the same manner; and, finally, I moisten my clean wire with strong sulphuric acid, and heat the substance with it in the flame, and watch for any indication of boric acid.

I have found that the presence of iron in operation I. can be instantly and accurately ascertained by moistening the residue fused on the platinum foil with fusion mixture and potassium nitrate, or by the nitrate alone, with strong, pure, nitric acid, and then adding a drop or two of potassium or ammonium sulphocyanide solution. The bright red colouration which results from this test if iron is present is an exceedingly delicate, characteristic, and infallible indication.

I have gone very carefully through Bunsen's elaborate system of film tests, but have only been able to find the metallic films of mercury (which, when treated by my method detailed above, show the scarlet iodide very well) and selenium, and the oxide films of cadmium, and lead and bismuth of much value in blowpipe analysis.

Professor Szabo's method of detecting calcium, barium, lithium, potassium, &c., in infusible or difficultly fusible silicates, I have, after many trials, found to be tedious and extremely uncertain in results. Mr Grenville Cole, who has paid considerable attention to this plan, particularly in connection with the determination of felspars, has devised a very simple and effective stand for holding the fragment of mineral to be tested, steadily, in any region of the flame, but no amount of invention, in my opinion, will much improve Szabo's method.

I have very slightly modified Von Kobell's Scale of Fusibility (see table of operation J. at the end of the paper).

Rapid and trustworthy tests are still required for the following metals:—Aluminium, beryllium, caesium, cerium, iridium, lanthanum, lithium, magnesium, nickel, potassium, rubidium,

[1] See paper by the author, "On the Macroscopic Determination of Igneous Rocks," in "Trans. Edin. Geol. Soc., vol. v., page 488; and also article by the same, "On the Rapid Decomposition of Insoluble, Natural, and Artificial Silicates for the purpose of Qualitative Analysis," in *Chemical News*, vol. lviii. No. 1518.

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thorium, tantalum, thallium, titanium, tungsten, uranium, vanadium, yttrium, and zirconium; and for the following non-metallic elements:—Boron, fluorine, and silicon. Of course *new* rapid satisfactory tests for any of the other elements are also always acceptable.

The Operations of Qualitative Blowpipe Analysis.

A. *Heating in the Closed Tube.*

Result.	Inference.
1. The substance changes colour,	One of the "heavy" metals present (*e.g.*, Sn, Sb, Pb, Cu, Bi, Hg, Cd, Cr, Fe, Zn, Ti, Nb).
2. The substance glows or phosphoresces, (Often seen better by heating powder on platinum foil.)	Fluorite, Willemite, Gadolinite, ZnO, &c.
3. The substance evolves water,	Hydrate.
The substance evolves water which has alkaline reaction,	Am. salts.
The substance evolves water which has acid reaction,	Volatile acid (HCl, HF, H_2SO_4, HNO_3, &c.) present.
4. The glass of tube above the assay is etched, and the vapour arising from the heated substance turns Brazil wood paper yellow,	Presence of fluorine.
5. The substance fuses,	The degree of fusibility of the substance is most probably 1, and certainly not more than 2 (Von Kobell's sale).
6. The substance carbonizes,	Organic compound.
Test any water given off; (1) if alkaline,	Nitrogenous body.
(2) If acid,	Non-nitrogenous.
7. A sublimate is formed on the cooler part of the tube,	Sulphur (yellow to reddish), selenium, tellurium (condenses in small drops with metalloidal lustre), osinium (sublimate of whitish drops with disagreeable odour), iodine (violet fumes, more especially if heated with $KHSO_4$ or H_2SO_4), Hg, As, Sb.
Heat another portion of the powdered substance mixed with about three times its bulk of fusion mixture.	
a. Odour of hartshorn evolved,	Presence of Am.
b. Odour of garlic evolved,	Presence of As.
c. Metallic sublimate which is—	
(*a*) Close on assay,	Sb.
(*b*) Well above assay,	Hg, As.
Pour into the tube one drop of conc. HNO_3, then one drop of KI; warm slightly.	
A scarlet substance formed on sides of tube,	Hg.
8. The residue is magnetic,	Fe, Ni, Co.
9. Heat strongly a little more of the powdered original substance with magnesium wire. Put in a drop of water, and smell.	
Odour of PH_3 (phosphine),	Presence of phosphorus.

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A. *Heating in the Closed Tube—continued.*

Result.	Inference.
10. Heat *strongly* a little of original powdered substance with soda flux (Na_2CO_3) and charcoal dust, then pour into tube a *little* hot water. The water assumes a purplish colour,	Tellurium.
11. Heat gently original substance with a little strong H_2SO_4.	
a. Substance effervesces (or does so with HCl or slightly warmed HNO_3),	CO_2. (Carefully distinguish between effervescence, and boiling of the liquid.)
b. Brownish vapours evolved with nitric odour,	Nitrate.
c. Brownish vapours evolved, which turn starch paper yellow,	Bromide.
d. Violet vapours evolved, which turn starch paper blue,	Iodide.
e. White pungent acid fumes, which etch the glass above the assay,	Fluoride.
f. White pungent acid fumes, which do not etch glass,	Chloride.
Confirm by heating a little more of original substance with H_2SO_4 and MnO_2. Chlorine gas evolved recognised by its odour and bleaching properties,	Chloride.

B. *Heating in the Open Tube.*

Result.	Inference.
1. Odour of SO_2 (burning sulphur) evolved	S. (The fumes redden moist litmus paper.)
Odour of garlic,	As.
Odour of decaying horse-radish,	Se.
2. Substance changes colour,	See previous table (A. 1).
3. Sublimate formed,	As, Sb, S, Se, Te, Bi, Pb, Hg, Mo.
a. When R. flame of blowpipe is directed on sublimate it becomes blue or copper-red,	Molybdenum.
b. The sublimate is dark brown when hot, yellow when cold,	Bi.
c. Sublimate is grayish. It fuses to clear drops, which solidify on cooling,	Te.
d. Steel gray sublimate,	Se.
e. Distinct white sublimate. Touch it with Am_2S, it becomes orange,	Sb.

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C. *Heating on Charcoal.*

Result.	Inference.
1. Characteristic odours evolved, - - - - These should be at once observed after a short exposure to the heat—*first* of the R.F., and *second* of the O.F.,	As, Se, S (see B. 1)
2. The substance deflagrates, - - - - -	Nitrates and certain other bodies very rich in oxygen.
3. The substance fuses readily, - - - - -	Fusibility not more higher than 2.
4. The substance swells up, - - - - -	Borax, Sassolite, Alum, &c.
and forms a glass on cooling - - -	Borax, Sassolite, &c.
5. After strong heating an infusible residue is left, which is	
a. Coloured, - - - - - - - - -	Cu, Co, Ni, Mn, Fe, Cr, Ti, &c.
or *b.* White or gray, - - - - - - - - which—	Ca, Sr, Mg, Zr, Al, Zn, and Sn (glow brightly), Ba, SiO_2, &c.
Is alkaline to test paper, - - - - -	Ca, Ba, Sr, Mg.
Moisten (*b*) with $Co(NO_3)_2$, and heat again. The mass assumes a	
Blue colour, - - - - - -	Al, SiO_2 (faint).
Violet colour, - - - - - -	Zr (dirty violet), P_2O_5 (rarely).
Pinkish colour on cooling, - - -	Mg, Ta (after long ignition).
Green colour, - - - - - -	Zn and Ti (yellowish green), Nb (dirty green), Sn (bluish green).
6. One or more sublimates or coatings are produced, which may be—	
a. Yellow on cooling, - - - - - -	Bi, Pb.
Heat a little more of the substance with Cu I + S in the R.F. A red sublimate is formed, - - - - - - -	Bi.
b. Yellowish-white on cooling, - - - -	In.
c. Brown-red on cooling, - - - -	Cd.
d. Red-brown to red (usually very slight), -	Ag.
e. Steel-gray, - - - - - - - - -	Se.
f. White, while hot and cold, - - - -	Sb, As, Tl, Te, Sulphides and Halogen Salts of the Alkalies, and Hg.
Touch the sublimate with a drop of Am_2S, and warm very slightly. The sublimate assumes an orange colour,	Sb.
g. Yellowish while hot, white on cooling, -	Zn, Sn (slight coat near assay), Mo.
7. A bead or beads or scales of metal produced, -	See Operation D.
8. The residue is magnetic, - - - - -	Fe, Ni, Co.
9. The substance is completely volatilised, - -	Stibnite, Bismuth, Tetradymite, Orpiment, Realgar, Arsenolite, Arsenic, Antimony, Bismuth, Valentinite, Cinnabar, Calomel, Iodic Mercury (and other rare Hg minerals), Salmiak, Tellurium, Allemontite, Organic bodies, &c.
10. The substance burns with a flame, - - -	Sulphur, Orpiment, Realgar, certain Organic bodies, &c.

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D. *Heating on Charcoal with Fusion Mixture in the R.F.*

Note.—If only a white infusible residue without incrustation was obtained in C., it is not necessary to do this operation.

Result.	Inference.
1. The substance is reduced to the metallic state. (The residue, after proper fusion, should always be pounded in a mortar and lixiviated.)	
a. The metal is yellow and malleable,	Gold.
b. The metal is white and malleable,	Ag (not easily oxidisable). Sn (easily oxidisable).
Heat the white metal for a moment with a very little strong HCl, and then add a drop of $AuCl_3$. The purple of Cassius is formed,	Sn (Tin).
c. The metal is bluish gray and malleable,	Pb (marks paper).
d. The metal is red and malleable,	Cu.
e. The metal is yellowish-white, and *somewhat* brittle,	Bi (confirm by 6 *a*, Operation C.).
f. The metal is bluish white and brittle,	Sb (easily volatile).
2. Sublimates or coatings formed,	See Operation C.
3. The residue is magnetic,	Fe, Co, Ni.
4. Place the residue fused with fusion mixture on a bright silver coin, and moisten with a little dilute HCl. A dark stain produced on the coin,	S. (This test can only be used in the absence of Se.)

E. *Heating on Plantinum Wire.*[1]

Dip the Pt. first in HCl or AgCl (it is advisable to try both separately), then hold in inner flame.

Result.	Inference.
1. The non-luminous Bunsen, lamp, or blowpipe flame is coloured—	
a. Golden yellow,	Na.
b. Pinkish violet,	K.
c. Yellow-red to brick-red,	Ca.
d. Purple-red to crimson,	Li.
e. Crimson,	Sr.
f. Yellowish green,	Ba, Mo.
g. Intense green, blue near assay,	Cu.
h. Green,	Te, Tl.
i. Blue,	$CuCl_2$, Se, Pb.
j. Greenish blue,	Sb, $CuBr_2$.
k. Light or grayish blue,	As.
2. Moisten substance with H_2SO_4, and heat in flame.	
a. Yellowish green colouration produced,	Boric acid.
b. Bluish green colouration produced,	P_2O_5.

[1] Infusible or difficultly. Silcates should first be fused with ammonium fluoride, then heated on platinum wire as above, and the flame observed by means of the spectroscope. (See paper, "On the Macroscopic Determination of Igneous Rocks," in the "Transactions" of this Society, vol. v. page 488.)

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F. *Heating on the Borax Bead.*

This need not be done if the residue in operation C. was white.

Result.	Inference.
1. The bead is coloured—	
a. Blue in both flames when cold,	Co.
b. Green in both flames when cold,	Cr.
c. Bluish green in O.F., red in R.F. when cold,	Cu.
d. Yellow in O.F., green in R.F. when cold,	V.
e. Yellow in O.F., bottle-green in R.F. when cold,	Fe, U (yellow green).
f. Yellow in O.F., brown in R.F. when cold,	W.
g. Rose colour in both flames when cold,	D.
h. Reddish brown in O.F., grey or colourless in R.F.,	Ni.
i. Violet (amethyst) in O.F., grey or colourless in R.F.,	Mn.

G. *Heating in the Microcosmic Salt Bead.*

Result.	Inference.
1. The whole or portion of the substance is insoluble in the bead (observe when hot),	SiO_2.
2. The substance is completely dissolved in the bead, and colours it—	
a. Violet in R.F. on cooling,	Ti, Nb (sometimes bluish).
b. Blue in R.F. on cooling,	W (brown while hot), Co.
c. Fine green in R.F. on cooling,	U.
3. Other colours as with Borax (*see* F.).	

H. *Heating on Asbestos Thread in the Bunsen Flame to produce a Metallic or Oxide Film on Porcelain (Bunsen's Film Tests).*

Result.	Inference.
1. *a.* The metallic film produced by heating in the upper reducing flame is red,	Se.
b. The metallic film is gray. When touched with strong HNO_3 and KI solution it becomes scarlet and yellow,	Hg.
2. *a.* The oxide film produced by heating in the upper oxidising flame is yellow,	Pb, Bi.
b. The oxide film is brown,	Cd.

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I. *Heating on Platinum Foil with Fusion Mixture and Potassium Nitrate* (KNO_3).

Result.	Inference.
1. A bluish green colour appears after the mass is fused,	Mn.
2. A yellow colour appears after the mass is fused,	Cr.
3. When the fused mass is touched with pure HNO_3 and potassium sulphocyanide, a bright red colouration is formed,	Fe.

J. *Heating on Platinum Forceps to determine the Fusibility of a Fragment of the Substance, by Von Kobell's Scale.*

Result.	Inference.
1. Easily fusible in candle flame,	Fus. 1 or less.
2. Difficultly fusible in candle flame,	Fus. from 1 to 2.
3. Infusible in candle flame, but easily before a good blowpipe flame,	Fus. from 2 to 3.
4. Difficultly fusible before the blowpipe	Fus. from 3 to 4.
5. Only fusible before the blowpipe in the very finest splinters,	Fus. from 4 to 5.
6. Infusible before the blowpipe,	Fus. 6.

Note.—Any good chemical text-book may be consulted for the meanings of the symbols employed in the above tables.

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ANNIVERSARY MEETING.

(21st November 1889.)

VII.—*Address on Recent Progress in Palæontology as regards Invertebrate Animals.* By H. ALLEYNE NICHOLSON, M.D., D.Sc., F.G.S., Regius Professor of Natural History in the University of Aberdeen.

THE most appropriate theme for an opening address at the commencement of the winter's work of a scientific society is, doubtless, that of a review of the existing condition of the science to which the society devotes its chief energies. "Taking stock" is a process as much to be commended in the domain of science as it is in that of commerce, with the advantage in the former case that the results brought out may be fairly counted upon beforehand as sure to show a considerable balance to the credit side of the account. In the present instance I do not feel competent to give you such a review of a subject so vast and so far-reaching as is the modern science of Geology. You will, however, perhaps permit me to give you a partial review of the present state of the science of Palæontology, which has many inosculations with Geology proper, and with which I am more directly concerned than I can claim to be with the latter. Twelve years ago, when called upon to discharge the same function as that which has fallen to my lot to-night, I ventured to give you an account of the progress which had been made by Palæontology along its entire line of frontier. To-night I shall not attempt to do so much, and I shall content myself with giving you an idea of how our knowledge stands to-day with regard to the leading groups of Invertebrate animals.

To one who has followed the fortunes of Palæontology for the last twenty years, no symptom of progress has been more marked, or more hopeful, than the gradual emancipation of the science from the bonds of old tradition, and its complete and successful vindication of its claim to be regarded as a distinct branch of Biology. The rational classification of the different departments of human knowledge has sometimes been looked upon as a matter of purely theoretical interest, having no practical bearings; but experience teaches us that the development of any branch of learning depends very largely upon the recognition by those who labour at it of the natural relations of their special field to allied subjects of investigation. If this be admitted, it must be allowed that the history of Palæontology in the past has

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been a singularly unfortunate one. In the earlier periods of its development, on the ground of its relations to the chronological history of the earth, Palæontology was generally regarded as a branch of Geology; and there can be no doubt but that its progress was thereby greatly retarded. For this erroneous conception of the scope and relations of Palæontology, palæontologists themselves were, doubtless, largely to blame, in so far as their methods were often unscientific, while the description of fossil remains was commonly undertaken upon a very insufficient acquaintance with the corresponding recent forms of life. This latter evil has, it is to be feared, not yet wholly disappeared, but it has unquestionably become greatly reduced in its dimensions, and we may fairly hope that it will in time become a thing of the past. No feature in the progress of Palæontology during the last twenty years has, in fact, been of more hopeful augury than the gradual and now universal recognition of the indissoluble alliance which subsists between *Palæontology*, or the study of the older forms of life, on the one hand, and *Neontology*, or the study of existing organisms, on the other hand. Not only are these two branches of Biology chronologically inseparable, since their respective domains are divided from one another by no visible barrier, but their methods of investigation are precisely similar, and they find a common basis in the theory of Evolution. If it be true, however, that Palæontology suffered in the past from being wrongly regarded as an outwork of Geology, it is possible that it would suffer an equal injury in the future were it to give up its existence as an independent branch of Biology, and were to submit to a complete fusion with the kindred branches of Neozoology and Neobotany. This fusion has recently been advocated in the pages of "*Nature*" by a distinguished English neontologist, who has dilated upon the advantage which would accrue to science by the "suppression" of palæontologists. It is, however, improbable that this view will be acquiesced in by palæontologists in general. On the Continent, at any rate, the whole tendency of scientific development of late years has been in the opposite direction, and the claims of Palæontology to rank as a distinct branch of Biology are now fully and ungrudgingly admitted. This is evinced, to mention one thing only, by the establishment of separate chairs of Palæontology in several of the German Universities, a step in advance which we may hope will ere long be taken by our own country also.

It would be impossible, of course, that I should give you to-night even the most general idea of the vast progress that has been made during the last ten years by the science of Palæontology as a whole. All that I can do in the time at my dis-

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posal is to briefly indicate the condition of our present knowledge with regard to the past history of the greater groups of Invertebrate animals, and to endeavour to point out the lines along which future advances are likely to be made. Even within this comparatively limited field it is out of the question that I should enter into details. I must content myself with merely bringing under your notice those points in our recently acquired knowledge of the fossil Invertebrates which have a phylogenetic significance, or which bear upon systematic classification, or throw light upon geological theories, or which, finally, have a special morphological importance.

As regards the *Foraminifera*, in the first place, the most important advance has been the establishment of the fact that the perforate or imperforate condition of the test is not, as formerly supposed, a point upon which a natural classification of the group can be founded. To the recognition of this fact, however, Palæontology has only indirectly contributed; and it cannot be said that we have obtained much fresh knowledge as to the phylogeny of the class. The long controversy as to *Eozoön* still lingers on, though the balance of evidence—even in the absence of a satisfactory petrological explanation of the "canal system"—is slowly, but apparently irresistibly, moving in favour of the view that this supposed Foraminifer is truly inorganic in its nature. If this should be fully established, the oldest known *Foraminifera* date from the Upper Cambrian or Ordovician series; and the best recognised forms of these are referable to the "arenaceous" division of the class, from which the calcareous *Foraminifera* have been later evolved. The two best known Ordovician *Foraminifera*, viz., *Saccammina* and *Girvanella*, both belong, in fact, to the simple family of the *Astrorhizidæ*, which may, therefore, be looked upon as one of the root-forms of the entire class. The former genus still survives in a practically unchanged form, while the latter apparently finds a near ally in the recent *Hyperammina* and *Syringammina*. Not only is *Girvanella* now known to enter largely into the composition of certain of the Ordovician limestones of both Britain and North America, but its minute and convoluted tubes have recently been recognised as occurring in limestones of later age, extending the range of the genus in time to at least the Jurassic period. Moreover, it has been shown by Mr Wethered that the spheres of some of the so-called "pisolites" of the Jurassic are really formed by the growth of colonies of *Girvanella* round a central nucleus, instead of their being—as generally supposed—of the nature of oolitic grains.

As regards the *Radiolaria*, our knowledge has been enormously increased during the last ten years, while we have at the same time been made painfully aware of the great gaps which still

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remain to be filled up. With the single exception of the genus *Dictyocha*, which ranges from the Chalk to the present day, all the known fossil Radiolarians belong to the group of the *Polycystina*. Until a few years ago, fossil Radiolarians were not known as occurring in rocks older than the Chalk. Thanks to the researches of various observers, chief among whom stands Dr Rüst, we now know that the remains of Radiolarians are by no means uncommon in various Jurassic deposits, occurring more particularly in beds having the character of hornstone or chert. Rüst has also indicated the probable presence of Radiolarians in rocks as old as the Silurian, at any rate. In this connection I may refer for a moment to the possibility that the minute spherical organisms which occur in some of the Ordovician cherts of the south of Scotland will be ultimately shown to be truly Radiolarian in nature. Owing to the imperfect state of preservation in which these bodies generally occur, it is impossible at present to speak decisively on this point; but such sections as I have examined afford a fair presumption in favour of the view that the little spheres in question are the remains of *Polycystines*.

An interesting point in connection with the Radiolarian hornstones of the Mesozoic period, and the chalk-like Radiolarian marls of Barbados and of various parts of Southern Europe and Northern Africa, is that these deposits seem to be clearly ancient representatives of the modern "Radiolarian ooze" of the deep sea. If this point be admitted—as it is admitted by Haeckel—then we have in these old accumulations indubitable "deep sea deposits;" and it cannot be asserted that no deposits similar to the deep-sea oozes of the present day are to be recognised among the stratified rocks which compose the greater part of the earth's crust. This admission will necessarily have an important bearing upon the modern theory that the present continental areas have been in the main regions of elevation, and the existing oceans in the main areas of depression, since the beginning of the Cambrian period, if not from still earlier times.

As regards the fossil *Sponges*, the researches of Zittel, Hinde, Sollas, and others, have worked during the last ten years what is little less than a revolution. Prior to the researches of Zittel, our knowledge of the fossil *Porifera* may be fairly said to have been in an absolutely chaotic condition. The true structure and affinities of the undoubted fossil Sponges were wholly unknown, or very imperfectly known, and numerous problematical organisms were relegated to the *Porifera*, simply because their ascertained morphological characters did not permit of their being definitely placed elsewhere. At present, on the contrary, the group of the *Porifera* has been subjected

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to a thorough investigation by microscopic methods of research, and has been shown to admit of sub-division into a number of well-defined orders, the past history of which is for the most part fairly well known. The two great groups of the Lithistid and Hexactinellid siliceous Sponges have been shown to date from the Upper Cambrian, and to be represented in later periods by a vast series of fossil types. We have become acquainted with the large and singular groups of the Calcisponges defined by Zittel under the name of *Pharetrones*—a group which ranges from the Devonian to the Maestricht Chalk, but seems to have no Kainozoic or recent representatives. Lastly, quite recently, Hinde has shown that there occur in different portions of the Mesozoic series vast numbers of minute calcareous Sponges which do not seem to differ in any essential respect from the small and delicate Calcisponges of the present day.

In connection with the recent investigations into the structure and distribution of the fossil Sponges, two points of general interest have been clearly established. In the first place, it has been shown that the flinty framework of the siliceous sponges is quite capable of undergoing solution during the process of fossilisation, and, indeed, commonly does so; the original skeleton under these circumstances being represented in the rock simply by a vacant space, or being ultimately replaced by some secondarily deposited substance, such as calcite, peroxide of iron, or iron pyrites. In the second place, it has been proved that Sponge spicules play a very important part in the accumulation of deposits of flint in various formations, as, for example, in the chert beds of the Carboniferous system, the siliceous sandstones of portions of the Cretaceous series, and the flints of the White Chalk.

In the great sub-kingdom of the *Cœlenterata*, progress of late years has been almost as signal as in the case of the *Porifera*, but the complexity of this subject is so great that I must restrict my observations on this head to a few points. As regards the *Hydrozoa*, perhaps the most notable advance has been the clear establishment of the Hydrozoal affinities of the great extinct group of the Stromatoporoids, which play so important a part in the construction of many of the older Palæozoic limestones. Though related on the one hand to the Hydrocorallines, and on the other hand to the *Hydractiniidæ*, the Stromatoporoids seem to constitute a distinct series of the *Hydrozoa*, with no direct modern representatives. Of the two leading genera of the group, *Stromatopora* itself is closely related to the recent *Millepora*, while *Actinostroma* is built upon the type of the existing *Hydractinia*. Until recently, the latest undoubted remains of Stromatoporoids were recorded from the Upper Devonian

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rocks, but Waagen has shown ("Salt Range Fossils," No. 7, 1877), that various remarkable fossils, more or less closely related to *Stromatopora* proper, occur in the "Productus Limestone" of India, the age of which is Permo-carboniferous. It is, moreover, very probable that certain at present imperfectly known Mesozoic fossils, such as those forming the genus *Actinospongia* of D'Orbigny, will ultimately be shown to be direct descendants of the essentially Palæozoic series of the Stromatoporoids.

The range of the true Hydrocorallines in time has also undergone a further extension, since it would appear tolerably certain that the singular fossils described by Professor P. M. Duncan, under the genera *Syringosphæra* and *Stoliczkaria* are really related to the modern genera *Allopora* and *Sporadopora*. These curious fossils are best known under the name of "Karakoram stones," as occurring in the Trias of Cashmir, but very similar or identical forms have been described by Reuss from the Alpine Trias.

With regard to the other great division of the Cœlenterates, viz., the *Actinozoa*, late researches have been so extensive, and their final bearings upon systematic classification are still so uncertain, that I must merely glance at some prominent points of interest. I am the more disposed to follow this course, as the subject is one of great complexity, and hardly admits of being rendered comprehensible unless treated in detail.

It is, of course, only with those *Actinozoa* which produce a hard skeleton or "coral" that the palæontologist is directly concerned, and such forms were grouped by Milne-Edwards and Haime under the three great divisions of the *Zoantharia*, *Rugosa*, and *Alcyonaria*. It is moreover only certain of the *Zoantharia* which produce a coral of the ordinary type; and these are commonly spoken of as the *Madreporaria*. We may therefore confine our attention to the three great groups of the *Madreporaria*—which, for our present purpose, may be considered as synonymous with *Zoantharia*—the *Rugosa*, and the *Alcyonaria*. As regards the Madreporarians and the Rugose corals, it was formerly believed that we had to deal with groups ordinally distinct from one another. The proper Madreporarians—including, roughly speaking, the Recent, Kainozoic, and Mesozoic coralligenous *Zoantharia*—were supposed to be characterised essentially by the hexameral symmetry of their parts; while the essentially Palæozoic Rugose corals were believed to be built upon a tetrameral plan. In recent times, on the contrary, it has been maintained that this supposed distinction between the ordinary *Madreporaria*, or "Hexacoralla," and the *Rugosa*, or "Tetracoralla," is entirely valueless, and that the two groups must be merged with one another. In the present incomplete state of our knowledge of many Palæozoic corals, it is hardly possible to

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arrive at a final decision; but the known facts point, I think, to the conclusion that a middle course between these two extremes will ultimately be found to best express the facts of nature. The existence of a hexameral or tetrameral symmetry appears, in the first place, to be a matter of little or no classificatory importance; and it would seem that no adequate reason exists for the exclusion from the *Madreporaria* of even such obviously tetrameral forms as *Stauria*. On the other hand, the more characteristic groups of the old order *Rugosa*—and notably the various forms which have the genera *Zaphrentis* and *Cyathophyllun* as their central types—are distinguished from the typical *Madreporaria* by the presence of a distinct bilateral symmetry, shown by the general arrangement and mode of growth of the septa, or by an exaggerated or reduced development of certain of these structures. A certain amount of bilateral symmetry is, however, recognisable in some of the Madreporarians, and even the typical symmetrical forms of this group exhibit many points of relationship with the typical unsymmetrical Rugose corals. Upon the whole, therefore, in the present state of our knowledge, the best course seems to be that of re-casting, rather than of totally discarding, the old order *Rugosa*, some of the types formerly included under this name being removed to recognised groups of the *Madreporaria*, while the others are considered provisionally as a special section of the latter division. In this way the *Rugosa* will cease to be a separate *order* of the Corals, and will, at same time, be considerably restricted.

The division of the *Madreporaria* (excluding the *Rugosa*) was divided by Milne-Edwards and Haime into the four great sections of the *Perforata*, *Aporosa*, *Tabulata*, and *Tubulosa*. The last of these may be dismissed, as clearly Alcyonarian in affinity, or as based on young forms of other corals. Time, also, will not permit of my noticing the very numerous points of interest which have of late years emerged in connection with the fossil *Aporosa* and *Perforata*. With regard to the division of the *Tabulata*, on the other hand, I must make a few remarks. As originally understood by its founders, this group included a large number of corals—mostly of Palæozoic age—of very different morphological type, which were united together by the common fact that the corallites are intersected by transverse partitions or "tabulæ." At the present day it is generally admitted that it is impossible to retain the division of the *Tabulata* in the old sense, and the only question is whether the group should be broken up and redistributed, or should be retained in some restricted form. Most of those who have specially investigated this subject have come to the conclusion that the former course is the best, and that the groups of corals forming the old division *Tabulata* can be dis-

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tributed among other recognised sections without a violation of natural affinities. Recently, however, some authorities, such as Neumayr, Frech, and Steinmann, have argued in favour of the retention of the *Tabulata*, in a restricted sense, as an independent group of Corals, of which *Favosites* and its allies form the central type. There is, no doubt, much that can be said in favour of this view, and I should not personally be unwilling to adopt it, but in this case I think it would be a regrettable and misleading course to retain the old *name* of *Tabulata*, which originally covered a much wider ground than that proposed by the authorities just mentioned, and which has always been understood in a totally different sense.

Coming next to the Alcyonarians, the only points that I can notice are the varied opinions which have been held as to the systematic position of *Syringopora* and its allies on the one hand, and of the *Heliolitidæ* on the other hand. By many good authorities the *Syringoporidæ* have been considered as Palæozoic representatives of the recent Organ-pipe corals (*Tubipora*). In this view I cannot acquiesce, and I consider that the evidence to hand would show, beyond reasonable doubt, that *Syringopora* and its allies must find a place in the neighbourhood of the *Favositidæ*, whether these latter be regarded as referable to the perforate Madreporarians or as a distinct division of Corals. As regards the *Heliolitidæ*, the researches of Moseley upon the recent *Heliopora* seemed, at first, to point to a clear affinity between these two types; and *Heliolites* and its allies were accordingly very generally referred to the family of the *Helioporidæ* and to the division of the *Alcyonaria*. More recent researches, however, have cast grave doubts upon the naturalness of this arrangement. There seems, in fact, to be little doubt that *Heliolites* must be held to have little or no real relationship with *Heliopora*, in spite of the close external resemblance between the coralla of the two types, as also of a curious identity in their mode of growth. Opinions still differ, however, as to the precise position of *Heliolites* and its allies, some regarding them (on the ground of their increasing by "cœnenchymal gemmation") as a peculiar group of the Alcyonarians, while others (on the ground of their possession of twelve rows of septa) consider them as truly Madreporarian, or as belonging to the same general section as *Favosites* and *Syringopora*.

Before leaving the *Cœlenterata*, a moment's consideration may be devoted to the strange and widely distributed Palæozoic fossils usually grouped together under the name of "Monticuliporoids." The position of this group in the zoological system has been hotly contested, and certainly cannot be said to be yet finally settled, some authorities regarding them as Cœlenterates, while

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others would refer them to the *Polyzoa*. My own leanings have been towards a reference of the Monticuliporoids to the *Cœlenterata*, but it must be freely admitted that there is much to be said in favour of the Polyzoan affinities of these perplexing organisms. In many obvious characters the Monticuliporoids approach certain groups of the Cyclostomatous *Polyzoa;* and if, as I have recently suggested, the singular structures known as "acanthopores" in the Monticuliporoids should prove to be homologous with the basal supports upon which the "avicularia" of certain *Polyzoa* are carried, there would be in this another strong ground for regarding the former as of Polyzoan affinities. On the other hand, all the known *Polyzoa* increase by the ordinary forms of gemmation, whereas the Monticuliporoids not only increase by budding, but also by fission. Moreover, certain Monticuliporoids exhibit the very peculiar form of budding which has been called "cœnenchymal gemmation"—a mode of increase otherwise only known to occur in such undoubted corals as *Heliopora* and *Heliolites* and its allies. Upon the whole, it may be suggested as not improbable that the Monticuliporoids really constitute an extinct group of which we have no modern representatives, and that they may stand in an intermediate position between the Cœlenterates and the Polyzoans, without, in the strict sense, actually belonging to either.

Our knowledge of the past history of the *Echinodermata* has been enormously extended of late years, but there is obviously much for us to learn before we shall be in a position to work out the phylogeny of the group. Most authorities now agree in dividing the phylum into the two primary sections of the *Echinozoa* and the *Pelmatozoa*, of which the latter are provided at one time or another of life, or permanently, with a flexible stalk of attachment, or are fixed by their base to foreign bodies. Under the head of *Pelmatozoa* are included the three classes of the Crinoids, Cystoids, and Blastoids, of which the first alone has any existing representatives. The *Pelmatozoa* may be regarded as nearer to the ancestral type of the Echinoderms than are any of the *Echinozoa;* and, according to the views of Neumayr, the Cystideans are to be looked upon as the central group of the entire phylum. Unfortunately, the class of the *Cystoidea*, as at present defined, includes three distinct groups, or orders, which differ widely from one another in structure; and much research will be required before the relationships of these to one another are rendered completely clear. Moreover, should Barrande's recently published statement be established—that the external ends of the pores in many diploporous Cystideans are covered by a thin calcareous membrane, and are thus closed to the exterior, it

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will be necessary to revise many of the generally accepted beliefs as to the structure of these ancient Echinoderms.

Our knowledge of the morphology of the Blastoids has been vastly increased by the exhaustive "Catalogue of the Blastoidea in the Collections of the British Museum," which we owe to the labours of Mr R. Etheridge, jun., and Dr P. Herbert Carpenter, and to the same authors we are indebted for a satisfactory arrangement of these puzzling organisms into minor groups. The only other point relating to the fossil Echinoderms which can be noticed here is the change in the generally accepted classification of the Crinoids which has been brought about by the recent investigations of Wachsmuth and Springer. These authorities, namely, have lately shown that the supposed morphological distinctions between the Palæocrinoids and the Neocrinoids can no longer be maintained in their entirety. We may conveniently retain these names as expressing a general stratigraphical distinction between the older and younger Crinoids, but we can no longer regard them as indicating well-defined morphological groups. On the contrary, the Crinoids would appear to fall naturally into three great orders, of which only one (the *Coadunata*) is wholly made up of Palæozoic types, whereas the other two (the *Inadunata* and *Articulata*) are composed in part of ancient and in part of more modern types.

The difficulties which environ the study of the fossil *Annelides* have by no means been removed, though in some directions our knowledge has been largely augmented by the researches of late years. The recognition by Dr Hinde, and subsequently by other observers, of the jaws of Errant Polychætous Annelides in the older strata of the earth's crust, from the Ordovician onwards, has shown that the Palæozoic seas must have been tenanted by vast numbers of Sea-worms essentially similar to existing types. The investigations of Rohon and Zittel have further rendered it probable that the ancient and minute fossils which have been so long known under the name of "Conodonts" are likewise really the remains of Annelides. Lastly, Nathorst's researches have supplied an experimental basis for the view long held by many palæontologists—that a large number of the so-called "Fucoids" of the older rocks are really of the nature of markings left by Sea-worms and other marine animals on the surface of soft mud.

Amongst the *Crustacea* much work has been done of late years in the description of new forms and the more complete elucidation of the morphological characters of types previously imperfectly known, but it is impossible to enter into this subject here. As regards points affecting systematic classification,

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naturalists have now generally accepted the order *Phyllocarida*, proposed by Packard for the reception of the *Ceratiocaridæ* and *Nebaliadæ*, both formerly included among the Phyllopods. We thus see in the recent *Nebalia* and its allies the last representatives of a very ancient line of marine Crustaceans, which, so far as known, commenced in the Cambrian rocks with the genera *Hymenocaris* and *Protocaris*, and which underwent a vast development in the Palæozoic rocks generally. On the other hand, considerable differences of opinion still obtain as to the propriety of the proposal by Claus that the King-crabs, the Eurypterids, and the Trilobites should be grouped together in a common division of Arthropods under the name of *Gigantostraca*. As to the close relationship between the King-crabs and the Eurypterids there is, of course, no doubt, but it would be difficult, in the present state of our knowledge, to frame such a definition of the *Gigantostraca* as would embrace the two orders just mentioned along with the *Trilobita*, and would at the same time exclude all the other groups of the Crustacea. Still larger divergence of opinion exists as to the affinities of these latter groups, some authorities holding to their Crustacean relations, while others would place them in the vicinity of the Scorpions, and others, again, view them as types intermediate between the *Crustacea* and the *Arachnida*. As regards the higher *Crustacea* there is no special point of interest to note, though it may be predicted with some confidence that future discoveries will show the Schizopods to have possessed a higher antiquity, and to be more largely represented as fossils than the facts at present known would warrant.

The progress of our knowledge of the structure and geological distribution of the air-breathing Arthropods within late years has been fully chronicled by Mr Scudder, to whose personal investigations recent advances have been largely due. One of the most striking discoveries in this department has been that of Scorpions in the Silurian rocks, recognised almost simultaneously by Lindström in Sweden, Dr John Hunter in Scotland, and Whitfield in North America. Though very similar in general aspect to existing types, all the Palæozoic Scorpions are regarded by Scudder as referable to a special group (the *Anthracoscorpii*), distinguished from the recent Scorpions (*Neoscorpii*) by the position of the dorsal eye-tubercles far forwards.

As regards the Insects, the most important step, from a systematic point of view, has been the establishment by Scudder of the order of the *Palæodictyoptera* for the reception of all the known Palæozoic Insects. As defined by Scudder, this order comprises generalised Insects in which there was an "incomplete" metamorphosis, and all the four wings were membranous,

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equally developed, and characterised by a simple type of neuration. Though constituting, in Mr Scudder's opinion, a single homogeneous group, the *Palæodictyoptera* are believed by this high authority to comprise four recognisable groups of types, representing the four existing orders of the *Orthoptera, Neuroptera, Rhynchota* (*Hemiptera*), and *Coleoptera*.

Few groups of organisms have proved more difficult of investigation, or more refractory to systematic treatment, than the fossil *Polyzoa*. Much has been done in recent times to bring this troublesome group into order, but much has yet to be accomplished before it will be possible to speak confidently as to many points of fundamental importance to the systematist. From the palæontologist's point of view, the only groups of *Polyzoa* which require consideration are the *Cyclostomata* and the *Cheilostomata*, of which the former division is the most ancient, while the latter holds the predominant place at the present day. The structure of the fossil *Polyzoa* is, however, so complex, and our knowledge of many types is still so incomplete, that it would be useless here to do more than draw attention to one or two points of general interest. So far as we know at present with certainty, no unequivocal representatives of the Cheilostomatous *Polyzoa* have been recognised in any Palæozoic formation ; though there are some ancient types which, on more complete examination, may turn out to be referable to this division of the class. Not only are the Palæozoic *Polyzoa* in the main, if not wholly, referable to the *Cyclostomata*, but many of these old types differ widely in structure from the later representatives of this division. Moreover, there are certain groups of Palæozoic organisms (such as the Monticuliporoids) which may ultimately prove to be Cyclostomatous *Polyzoa*, but the systematic position of which is at present in doubt; so that it is difficult to frame any general conclusions as to the distinctive features of the Palæozoic *Polyzoa* as a whole. One interesting point may, however, be glanced at, viz., the occurrence in the skeleton of various Palæozoic *Cyclostomata* of thickened tubes which pass deeply into the substance of the polyzoary, and have a considerable resemblance to the so-called "acanthopores" of the Monticuliporoids. The structures to which I refer have been recognised by Mr John Young in several Fenestellids, and are known to occur in various other types. It may be suggested, with considerable probability, that the tubes alluded to served for the support of "avicularia," a view which is borne out by the fact that the avicularia of the recent *Retepora* are carried upon thickened tubes of an apparently similar nature.

With regard to both the *Brachiopoda* and the *Mollusca* proper, anything that can fitly be said here must be of the very briefest.

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A vast number of fossil types of these great sections of Invertebrates have been described within late years, and our knowledge, both morphological and systematic, has advanced in all directions. No better evidence of this could be wished than is afforded by Fischer's great "Manuel de Conchyliologie," which to the systematic malacologist may be said to mark an epoch. A classification of the *Brachiopoda*, which is to a large extent new, has been recently proposed by Neumayr, but further knowledge alone will decide how far this arrangement is really in accordance with natural affinities. As regards the Lamellibranchs, a thoroughly satisfactory division into primary sections is still to be found; but Fischer has done much to arrange the class in natural groups, which may be conveniently termed "orders," though it cannot be asserted that they have a value equivalent to that of the divisions known by the same name among Vertebrate animals. Through the exertions of Lindström, De Koninck, and other palæontologists much has been done of late to clear up controverted points relating to the structure and affinities of many fossil Gastropods; and the general classification of the Univalves has undergone much improvement.

Pelseneer, further, has shown that the *Pteropoda*, instead of constituting a separate class of the *Mollusca*, should be looked upon rather as a modified division of the Branchiate Gastropods. This observer, however, has raised certain points relating to some of the fossils usually regarded as belonging to the Pteropods, to which I may briefly refer. Dr Pelseneer, namely, is sceptical as to the existence of any Palæozoic fossils which can be regarded as truly referable to the *Pteropoda*, this conclusion being seemingly to some extent based on the apparent absence of Pteropods in the Mesozoic rocks—a piece of negative evidence to which palæontologists generally would be indisposed to attach any importance. The Palæozoic fossils which have usually been referred to the Pteropods are of varied nature, but they mostly belong to the genera *Conularia*, *Hyolithes* (*Theca*), and *Tentaculites*, or to allied genera; while some have been referred to the existing genus *Styliola* or *Clio*. With regard to *Conularia* and *Hyolithes*, it must be admitted that it is at present impossible to speak with any certainty, since the forms included in the groups typified by these genera are undoubtedly widely different from any Pteropods now in existence, and, in particular, are much larger in point of size than are the normal members of the latter. On the other hand, I fail to recognise in those Silurian and Devonian "*Styliolæ*" which I have personally investigated, any distinction which would serve to satisfactorily separate them from the recent genus *Styliola*, and certainly nothing which would lead one to doubt that they are genuine Pteropods. Thus,

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the shell of *Styliola* (*Creseis*) *fissurella*, from the Devonian rocks of North America, is a very delicate conical tube, of circular section, without internal partitions, and of an average length of two or three millimetres. (Fig. 1.) Its surface is without annulations, and is sometimes smooth, though in some examples the surface may show fine transverse striæ or even longitudinal striations. Moreover, the apex of the tube (fig. 2, A and B) is commonly slightly bulbous, and is thus marked off as an "initial chamber" from the rest of the shell. This interesting little fossil is excessively abundant in certain of the Devonian rocks of North America, and sometimes gives rise by the accumulation of its tubes to thin bands of limestone (fig. 1), which might be fairly compared with a modern "Pteropod-ooze." Dr Pelseneer refuses to admit the Pteropodous nature of this and other similar fossils, on the grounds of their great comparative size, the alleged absence of an embryonic shell, and the fact that no existing species of *Clio* has the shell longitudinally striated. But these objections cannot be considered as valid in the case of *Styliola fissurella*, since the tube of this fossil is *smaller* in point of size than that of some existing species of *Clio*, an embryonic shell or "initial chamber" *is* present, and the striation of the surface cannot be held to be a character of any systematic importance. Upon the whole, therefore, I do not see any sufficient reason for denying the Pteropodous nature of *Styliola fissurella*, nor can I attach any importance to the fact that no similar types have hitherto been detected throughout the great pile of strata intervening between the Devonian and the Miocene Tertiary.

Fig. 1.—Thin section of limestone from the Devonian rocks of Canandaigua, North America, composed almost entirely of the tubes of *Styliola fissurella*, enlarged twenty times.

With regard to *Tentaculites*, little can be said here, as the subject is one of considerable complexity, and it must be admitted that, in the present state of our knowledge, the affinities of the genus cannot be finally determined. In this well-known Palæozoic genus, the shell is a straight conical tube, from half a centimetre to three centimetres in length, with a closed pointed apex and a circular aperture, the internal cavity being sometimes open, sometimes crossed by transverse partitions. The surface is marked by characteristic elevated annulations, the spaces

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between which exhibit fine encircling striæ, sometimes with longitudinal striations as well. The apex of the shell (fig. 2, C) is sometimes bulbiform, its starting-point being thus a dilated chamber, apparently similar in character to the "embryonic shell" of *Clio* and other Pteropods. The microscopic structure of the tube, in such forms of the genus as I have examined, is complex, the outer layer of the shell being traversed by a system of exceedingly fine transverse tubuli; but this point need not be discussed here. Pelseneer denies the Pteropodous nature of *Tentaculites* entirely, as also does Neumayr; and the latter endorses a view that has been commonly held, viz., that the genus is really referable to the Tubicolar Annelides. Now it is undeniable that the tube of *Tentaculites* is very similar in general aspect to that of such Tubicolar Annelides as *Cornulites* and *Ortonia*; and it also seems more than likely that *some* of the forms which have been placed under *Tentaculites* really are Annelidan. This is particularly the case with certain *curved* and longitudinally-striated tubes which have been described as species of *Tentaculites*. I am not prepared, however, to admit that the Annelidan nature of the *typical* forms of *Tentaculites* has been proved. On the contrary, it seems to me that much may yet be said for the view that the genus is really an ancient and abnormal type of the *Pteropoda*. The grounds upon which I base this belief are briefly the following :—

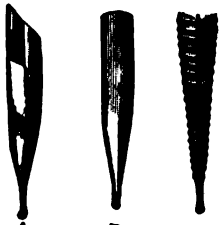

Fig. 2.—A and B, Specimens of *Styliola* (*Creseis*) *fissurella*, Hall, from the Devonian rocks (Hamilton Group) of North America, enlarged about six times, showing the embryonic shell at the apex; C, Apical portion of the tube of *Tentaculites gracilistriatus*, from the same formation, enlarged to show the embryonic shell. (After Hall.)

1. The tubes of *Tentaculites* are invariably *free*, and have never been shown to be attached at any period of growth to any foreign body. Indeed, they are sometimes found strewn in myriads over the surfaces of the strata, in a manner precisely similar to what we should expect had they been surface-living organisms which had dropped to the bottom of the sea after death.

2. The presence in some cases of a distinct bulbiform enlargement at the apex of the tube reminds us strongly of the "initial chamber" of the shell of the Pteropods.

3. The microscopic structure of the tube, though not distinctly Pteropodous, is totally unlike that of *Cornulites*, which, on the theory of the Annelidan nature of *Tentaculites*, would undoubtedly be the nearest ally of the latter.

As regards the remaining groups of the *Mollusca*, no points of special palæontological importance have emerged of late years

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with regard to the classes of the *Polyplacophora* and the *Scaphopoda*, and it would lead me altogether too far if I were to attempt to discuss the changes which the last ten years have brought about as regards our knowledge of the fossil forms of the great division of the *Cephalopoda*. It is enough to say that while our knowledge of the past history of both the Tetrabranchiate and Dibranchiate divisions of the Cephalopods has been enormously widened, the systematic arrangement of the fossil groups has at the same time become correspondingly improved. Those who wish to make themselves acquainted with the modern views as to the structure and classification of the fossil Cephalopods may safely be referred to the masterly "Handbuch der Palæontologie" of von Zittel, in which is given an admirable general view of the whole of this intricate subject. The most important problem, from the systematist's point of view, which still awaits its final solution relates to the affinities of the *Ammonoidea*. This great extinct group of Cephalopods is regarded by some authorities as forming a special division standing in an intermediate position between the Tetrabranchiates and the Dibranchiates, while others would regard it as actually referable to the Dibranchiates. Most palæontologists, however, still regard the Ammonoids as most nearly related to the Nautiloids, and, therefore, as true Tetrabranchiates.

One word further may be said as to the strange group of the *Urochorda*, under which name many naturalists now include the Tunicates; and also as to the anomalous genus *Balanoglossus*, which latter constitutes alone the group of the *Enteropneusta*. The palæontological history of these two groups is, however, still almost a complete blank. Nor is this to be wondered at, since the animals in question are little or not at all capable of leaving any traces of their past existence in the rocks. Many existing Tunicates, both simple and compound, are known, however, to possess in their tissues numerous minute calcareous spicules; and by the help of these it may ultimately be found possible to trace backwards the history of these singular organisms. As a matter of fact, indeed, the minute spicules of a Tunicate (a species of *Leptoclinum*) have recently been discovered in the Pliocene beds of St Erth. *Balanoglossus*, again, has no hard structures capable of preservation in the fossil state, but it has the power of surrounding itself with a mucous tube, and it is, therefore, possible that it might have left recognisable traces of its past presence in the sand of ancient sea-shores.

It is out of the question to enter here and now into any consideration of the broad and general theoretical views which may be legitimately based on the known facts of Palæontology, as this science stands to-day. I may, however, bring the present

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scattered remarks to a conclusion by pointing out that the ascertained facts of Palæontology indicate, with an ever-increasing clearness, the existence of some general law of Evolution, by the operation of which new forms of life have been successively introduced upon the earth. As to the precise *modus operandi* of this general law, Palæontology does not, in my opinion, at present afford a decisive answer. That *one* great factor in the process has been the operation of "Natural Selection," as explained and defined by Darwin, does not, I think, admit of reasonable doubt. That "Natural Selection" has been the *sole* agency at work is, however, a different and more doubtful point; and Palæontology, at any rate, does not seem to me to be yet in the position to supply the final solution to this most difficult and complex problem.

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY,

SESSION 1889-90.

VIII.—*Notes on Faults.* (*Abstract.*) By J. G. GOODCHILD, H.M. Geological Survey, F.G.S., *Lecturer on Geology and Palæontology at the Heriot-Watt College.*

(Read 2nd May 1889.)

AFTER reviewing some of the chief points of interest in connection with faults in general, the author went on to discuss, (1) their several modes of formation, (2) their prevailing directions, (3) their relative ages, and (4) their relations to mineral veins.

(1) The initiation of most of the larger faults appears to have taken place under plutonic conditions, or, at least, under conditions of great superincumbent pressure. Probably, in nearly every case, such faults are due to the unequal yielding of rock masses before tangential thrusts, which were being exerted while that part of the earth's crust was undergoing *upheaval.* The leading directions of fracture in such cases would be parallel to those of the thrusts themselves; modified (1) more or less by the prevalent directions of the joints, (2) by the interferences caused by pre-existing lines of fault. Probably, in all such cases, plutonic faults take the form of a series of apposed anticlinals and synclinals—the plane of disruption coinciding with the plane of the fault. [This phenomenon was illustrated by pressing together the opposite ends of a sheet of cardboard, which had been slit from the middle across to near each of the opposite edges. The endlong thrust being applied in the direction of the slit, the cardboard on one side was bent into an upfold or anticlinal, while the cardboard on

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the opposite side was bent into a downfold or synclinal, so that the "throw" was greatest in the middle.]

It was pointed out that when once such a plane of weakness has been formed, it tends, for ever, to guide the direction of any newer dislocations affecting that particular part of the earth's crust, and may thus be repeated again and again, and consequently affect the whole of the strata that may, from time to time, come to be deposited over that particular spot. In this way, for example, a fault initiated in Archæan times may be repeated in Cambrian or in Silurian times, and may guide the directions of dislocations affecting the rocks of Carboniferous age, or even newer strata. Faults might thus be classed as Primary or Secondary, in cases where it is possible to make out their ages.

Intrusions of plutonic rocks tend to weld up such planes of weakness, as do also thick and continuous masses of vein quartz or minerals of similar hardness.

It can be shewn to have happened, in a few cases, that the newer movement along a fault plane has taken place in the opposite direction to that of the older. So it is quite possible that a newer group of strata may present the anomaly of being dislocated to a greater extent than that of the older strata beneath; the older rocks in this case being moved back again nearly or quite to their original position, and the older fault neutralised. This appears to have been the case with the Pennine Fault in parts of eastern Westmorland.

Sometimes faults of small magnitude have been formed during the upheaval of an area, and have resulted from wedge-shaped masses of rock giving way along joints, and either dropping to a lower level, or else remaining stationary while the rock adjoining moved past in an upward direction. Such faults might be expected to have hades of low angle, especially where the strata traversed were of such a nature as to give out readily before lateral pressure or thrust. The hade of a fault in most cases is determined by the direction of the forces acting upon it; but it is also largely influenced by what may be termed the "extensibility" of the rocks affected; shales, for example, being much more easily drawn out, or thrust in, along their bedding planes, than the associated sandstones and limestones.

Where the orientation of a newer set of faults differed very much from that of the older, the pre-existing planes of weakness usually interfered more or less with the direction of the newer faults. As a consequence it frequently occurs (in fact it is almost always the rule), that the disrupted parts of the newer set of faults differ from each other considerably in their throw, their hade, their direction, their position, their number, and

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even in their mineral contents, on opposite sides of the older line of disturbances. Northern English metal-miners distinguish these phenomena of interference as the "Trail;" the older line of disturbance being said to "trail" the newer, or the set interfered with. A fault, for example, is traced up to one of a different direction, on meeting which, the two merge into one for a variable distance, and then separate again, at a point perhaps fifty yards or more from the first point of junction. In any case, the fault is invariably "trailed" on the obtuse side of the angle formed by the older set and the newer. Very commonly, there is more or less difference between the one part and the other of the trailed fault—a fact which is easily enough explained on the supposition that the cross fault that trails is the older, and the trailed fault the newer, but is incapable of any rational explanation on the opposite view of their relative ages, which is the one commonly accepted. True "heaves," where a fault itself is faulted, are also not uncommon; but most of the breaks of faults, as well as most of the curved courses laid down upon maps, are referable to the trail just noticed.

In the north of England, and, indeed over a much larger area, there is a marked absence of faults having a true north and south direction. I have never yet met with a single authenticated instance. I have before remarked the same fact in connection with joints.

As regards the orientation of faults some curious facts should be better known than they seem to be. In the mining areas of the north of England the faults readily group themselves into five or six sets, each of which may exist in combination with any of the others. These may be noticed here in discussing their relative ages. If we may judge of the relative ages of faults (as the writer believes we may safely do) by the phenomena of the "heaves" on the one hand, and the "trail" on the other, then the oldest set is those whose directions range nearly with the present magnetic north; *i.e.*, about 20° west of true north. These trail all the others, and are themselves heaved by any one of the sets associated. Next in succession are those whose prevailing directions are about north-west and south-east. Then come the north-north-easterly set. Still newer are those ranging about (the present) magnetic east. Latest of all, trailed by all the others, and in their turn heaving all the rest, are those whose orientation is approximately due east.

The filling of some one set of these faults with ores, while the associated faults contain little of value, has long been a fertile source of perplexity to students of mining geology. But if the view be accepted that the metalliferous contents of

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mineral veins have been introduced by the agency of thermal springs rising towards the surface during *upheaval*, when the sides of the veins were periodically *stretched* wider and wider asunder, then the difficulty ought no longer to exist. For during upheaval the prevailing direction of the terrestrial undulations would certainly tend to keep one set of fissures open, to the exclusion of the rest. Those that remained closed would be less likely to act as upward channels for the thermal waters than would the other sets, kept open by the undulation strains; so these would become filled, while the others would remain much as they were before, either filled with other minerals introduced under different conditions, or else devoid of metalliferous contents altogether.[1]

Some observations were then made upon the disturbances of the strata contiguous to faults, consequent upon differential upheaval. Where the rocks are much bent in this relation the northern English miners speak of the phenomenon as the "Burr," a term that might be introduced into geological terminology with advantage.

Reversed faults were noticed in some detail. The writer briefly noticed the overthrusts characteristic of regions that have undergone plutonic disturbances, and then went on more particularly to deal with the smaller faults of more common occurrence. He especially referred to the reversed faults so well displayed upon the banded slates (fine tuffs) of the English Lake District. It was pointed out that these are due, in nearly every case, to the irregular *downward* pressure exerted upon the unconsolidated tuffs during deposition, by their having been rolled out beneath heavy floods of molten rock (lava); or to their having been subjected to endlong thrusts acting obliquely from above downwards, and arising from the same cause.

The reversed faults so common in glacial deposits he attributed to an analogous cause, *i.e.*, to the irregular downsettling of the melting ice-sheet upon the unconsolidated mass of sediment that was being released from the ice as it melted away. The "striated pavements" were only another form of reversed faults due to the same irregular downward movement of the ice-sheet, as melting let it down by fits and starts upon the sediment of mud and stones being liberated between its base and the rock surface below.

[1] See J. G. Goodchild, "Metalliferous Deposits," Proc. Geol. Association.

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IX.—*On some Abnormal Deposits of Limestone.*[1] (*Abstract.*) By J. G. GOODCHILD, H.M. Geological Survey, F.G.S., *Lecturer on Geology and Palæontology at the Heriot-Watt College.*

(Read 19th December 1889.)

THE author reviewed several of the different modes whereby limestones may have been formed, his chief conclusion being that a variable, but often large, percentage of the constituent matter of nearly all limestones is of the nature of a chemical precipitate, due to the reactions of matters of organic origin upon the sulphate of lime in sea-water. [When the paper was read the author advocated the view that the carbonate of lime secreted by aquatic animals—and therefore the chief organic constituents of limestones—was obtained by the organisms from the *sulphate of lime* existing in solution in sea-water, and he gave several reasons for doubting whether any of the carbonate of lime of organic origin could have been, in any case, assimilated direct. The author was not aware until after the paper was read, that these points had been already demonstrated by Messrs Irvine and Woodhead. (Proc. Roy. Soc. Edin., vol. xvi., p. 324.) The author had independently arrived at this conclusion by an entirely different line of reasoning.] Some reference was made to limestones that are entirely of inorganic origin. It was pointed out that where basic igneous rocks are undergoing decomposition, or other changes in composition, carbonate of lime is one of the substances liberated; and this is often redeposited at lower levels. As a rule such deposits consist of calcspar and are more or less crystalline; but in some few instances the mineral is left nearly in an amorphous form, hardly, if at all, distinguishable from sedimentary limestone. Some well-banded and fine textured limestones traversing the bedding planes of the volcanic rocks on the shore east of North Berwick appear to be of this nature. Other illustrations were referred to. More commonly the decomposition of the ferro-magnesian silicates in rocks of basic composition gave rise to beds of native dolomite. Some examples were adduced.

[1] Part of this paper was published in the *Geological Magazine* for February 1890, under the title of "The Paste of Limestones."

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X.—*Our Coal Resources (with Diagram).* By Professor EDWARD HULL, LL.D. F.R.S., F.G.S., *Director of the Geological Survey of Ireland.*

(Read 16th January 1890.)

THE subject of this paper formed the chief topic of the address of Sir William (now Lord) Armstrong, when the British Association met at Newcastle-on-Tyne in the year 1863. Since then a quarter of a century has elapsed, manufactures and commercial undertakings have progressed by leaps and bounds, and, concurrently, coal-mining has been developed to an extent much beyond the anticipations of many who looked at that time with some anxiety on the rapid increase of coal-consumption, especially in some districts of more than ordinary commercial activity. At that time the recent discoveries of extensive deposits of Liassic iron ore in the North Riding of Yorkshire, in Lincolnshire, Northamptonshire, and Oxfordshire, together with those of the richer hæmatites of North Lancashire and Cumberland, had given a powerful impulse to the manufacture of iron; and this was sustained by the gradual substitution of iron for wood in shipbuilding and other arts. The quantity of pig-iron smelted in the British Isles at the beginning of the century was only about 200,000 tons; in a quarter of a century (1825) the estimated amount (as given by the late Professor Jevons) was 581,000 tons; in 1854 the production of pig-iron had reached 3,069,838 tons; and in 1863, the year of the previous meeting of the Association at Newcastle, the production had reached 4,510,041 tons; a development largely due to the great expansion of the iron trade on the banks of the Tees. In 1886 the quantity of pig-iron manufactured reached 7,009,754 tons; and in 1887 (the last year for which returns have been issued by the Board of Trade), 7,559,518, an advance of over half a million of tons on the previous year. Thus the increase in the production of iron keeps pace with that of coal. The "wooden walls" of old England, which did such good service in the time of the Spanish Armada, and, later still, in that of Nelson, are being replaced by those of iron and steel. Sir Frederick Bramwell, in his presidential address at Bath, has instituted a fanciful, but very suggestive, comparison between a Grecian galley propelled by oars, one of those triremes of which Homer sang so proudly, with a modern Atlantic liner; and he shows us how (supposing the ship could hold the number of men) the effect produced by a large prime mover, or set of marine engines of the present day, would exceed that of 117,000 men at work, with an equal number of reserves.[1] But I must not further pursue this at-

[1] Address, 1888. Rep. Brit. Assoc., Bath, p. 8, 1888.

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tractive subject; my only object in referring to it being to show how iron has become the most important substance in the arts of the nineteenth century, as it is the most abundant metallic substance in nature. It is worthy of remark, that if British coal is a product of but one geological formation, viz., the Carboniferous, iron, in its various compound forms, is a product of many, and occurs in sufficient quantities to be productively workable in no fewer than eight formations or groups of strata, viz., as hæmatite in the Silurian and Lower Carboniferous; as clay-ironstone in the coal-measures; as an earthy protoxide in the Lias and Oolite and Wealden; as a silicious peroxide in the Lower Greensand; and as an aluminous peroxide in the plateau-basalts of the Tertiary period. With such extensive stores of iron ore, and abundance of coal wherewith to convert it into its metallic state, it would have been our own fault if we had not, during the nineteenth century, taken a leading position amongst the manufacturing states of the world.

In referring to the present resources of our coal-fields it may be well to glance back at the discussions which have taken place on this subject from time to time during the present century. From the time of John Williams, who published his "Natural History of the Mineral Kingdom" in 1789, down to that of the late Professor W. Stanley Jevons, who treated the subject in a masterly manner in his work on "The Coal Question," published in 1865, various authors have essayed to forecast the future of our coal resources. It was only, however, when the Government Geological Survey had so far completed a sufficient number of maps, sections, and reports on the coal-fields of the British Isles as to enable us to make approximately accurate estimates of the amount of coal therein, that we obtained one, at least, of the factors available in the problem—"For how long shall our coal resources last?" This state of progress was reached shortly after the commencement of the present half-century; for although the coal-fields of Newcastle and Cumberland had not at that time been geologically surveyed, their resources had been pretty fully investigated by several mining engineers, such as Hugh Taylor, G. Greenwell, and T. Y. Hall, and the available quantity of coal in the Newcastle field was known with sufficient accuracy.

The question of the probable duration of our coal supply was brought prominently into notice during the debates on the Commercial Treaty with France in the Parliament of 1860, and the want, then acutely felt, of any estimates of a reliable character regarding the available quantity of coal, forced itself upon the public attention. Having been engaged in the Geological Survey of the central parts of England for several years previously, my own attention was called to this subject from time to time, and

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I determined, with such aid as I could obtain both from individuals and from available maps, sections, and other documents, to attempt a solution of this important problem. The result is pretty generally known. Taking the limit of workable depth at 4000 feet, and excluding from my calculation seams under two feet in thickness, I found that there existed a quantity of coal equal to, at least, 79,843,000,000 tons, which, at the then rate of production, was sufficient to last for one thousand years. This was the result published in the first edition of "The Coal-fields of Great Britain,"[1] and was afterwards somewhat extended (in 1864) to 83,544,000,000 tons.[2] This latter amount is that adopted by the late Professor Jevons in his "Coal Question,"[3] while the former was that adopted by Lord Armstrong in his review of the subject in the city of Newcastle on the occasion of the meeting of the British Association in 1863. By the report of the Royal Coal Commission, under the presidency of the Duke of Argyle, issued in 1871, very full details of the resources of all the coal-fields of the British Isles, both visible and concealed under newer formations, have been placed within reach of the public. The estimates given in this important document, drawn up by gentlemen of experience and with great local knowledge of their several districts, somewhat exceed those arrived at by myself in 1860 and 1864. In one thing we agree, the Commissioners adopted as a practical limit of depth that of 4000 feet, assumed by myself in my original estimates; but we differ in one special point, viz., that they have included seams between one and two feet in thickness,[4] which I had excluded. I still consider this to have been a mistake on their part, because such thin seams as these, however it may be possible and profitable to work them at small depths, could never be exploited where the depth exceeds one, two, or three thousand feet.[5] I think we may fairly conclude that it is only seams which are good as to quality, and are also of a thickness of two or three feet and upwards, that will be profitably worked where the depth becomes considerable. On these grounds I am disposed to adhere to a great extent to my second estimate of 83,544,000,000 tons rather than that of 136,025,000,000 tons, arrived at by the Commissioners, and corrected up to the year 1880. If we were to take

[1] First Edition, published in 1861. [2] Journal of Science, No. 1, p. 33.
[3] First Edition, published 1865.
[4] The Royal Commission also very properly included estimates of quantities under certain districts overspread by formations newer than the Carboniferous. In this they were fully justified, as I have admitted in another place.
[5] In mining thin seams of coal part of the roof or floor of the seam has also to be cut away in order to give the miners necessary room; this involves increased expense in working. At the same time it is true that, in some cases, thin seams may be worked at a profit, when of good quality, when once the shafts have been sunk, and the machinery set up for working thicker seams.

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the consumption of coal in the near future at 200,000,000 tons per annum, the former would suffice for 417 years, the latter for 680 years, round numbers; but this is not a calculation on which I lay much stress.

We now come to the consideration of the rate of progress in coal production. This has been most remarkable within the last half century, and shows no signs that it has as yet reached its upper limit. At the commencement of this century the amount of coal raised in the British Islands probably did not exceed ten millions of tons per annum, of which, according to Mr T. J. Taylor, 2,520,075 tons were exported from Newcastle and neighbouring ports.[1] In 1830 the quantity was about 28,700,000 tons; in 1860 it had reached 80,042,698 tons, and the quantity for the year 1888 has more than doubled that of 1860, for it has reached (in round numbers) 170,000,000 tons.[2] There is reason to believe that between the beginning of this century and the year 1875 the output of coal has more than doubled itself for each successive quarter of a century; so that if this ratio of increase is maintained until the year 1900, the output will have reached (in round numbers) about 263,000,000 tons. Knowing, by past experience, the danger of forecasting the future, I only advance this as a highly problematical hypothesis. I must refer those who delight in such calculations to Mr Jevons' work on "The Coal Question."

The publication of the "Mineral Statistics of Great Britain," collected and arranged by the late Mr Robert Hunt, and now continued by the Inspector of Mines, and issued by the Home Office, has enabled us to ascertain with great accuracy the coal-production of the United Kingdom since the year 1854, when the first volume of the "Mineral Statistics" was issued. Relying on the data thus afforded, we can show the rate of progress of coal-mining, and the oscillations which have taken place at intervals, and thus we may also, to some slight extent, forecast the near future. I have constructed a diagram showing the rate of coal production in Great Britain during the present century, and it will be observed, that although there has been on the whole period an increase more or less rapid, yet there have been, since 1854, years of stagnation or of actual retrogression in the production of coal. (See Table, p. 87.)

The periods of rapid increase are as follows:—

Between the years 1858-61
" " 1870-72
" " 1879-81
" " 1887-88

[1] Taylor's "Archæology of the Coal Trade," pp. 177 and 204.

[2] The actual amount from the Report issued by H.M Inspectors of Mines is 169,935,219 tons for the year 1888.

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Those of stagnation are as follows :—

Between the years		1854-58
„	„	1861-63
„	„	1867-69
„	„	1873-75
„	„	1877-79
„	„	1883-86

These figures may be regarded as pretty sure indices to the state of trade and manufactures for the respective years, and particularly of our iron trade, and this latter is the barometer by which we can measure the condition of all our industries, including that of coal-mining.[1]

If iron is largely in demand, it shows that various manufactures are in a thriving condition, and the demand of iron creates a demand for coal wherewith to smelt the ores, and convert the raw metal into its innumerable artificial uses. This view will be found generally to hold good on comparing the years of expansion or stagnation in the iron and coal industries as furnished by the "Mining and Mineral Statistics of the United Kingdom," although the effect of the coal trade on the iron trade is not always instantaneous.

I now proceed to consider the manner in which the coal-production is affecting special coal-districts, or coal-fields. Since the year 1860 our coal resources have been reduced by about 3,640,000,000 tons, and this quantity has been somewhat unequally distributed amongst the coal-producing districts, in some of which production has enormously increased, while in others it has remained stationary or declined.

If we take the returns of the output from the different coal-fields for the years 1860, 1878, and 1888, we may be able to form a very fair idea of those which are progressive, stationary, or retrogressive. Other years might be adopted for the purpose of comparison, but the result would be probably pretty much the same ; and in order to obtain the most recent data, I have also brought in the returns for the year 1887. With these returns we find the following to be the *progressive coal fields.*

Here I take the opportunity of acknowledging the assistance and information afforded by several of H.M. Inspectors of Mines to whom I applied in special cases, particularly to Mr Joseph Dickenson, Mr W. Beattie Scott, Mr Thomas Wynne, Mr Henry Hall, and Mr A. H. Stokes.

[1] It will be recollected that Lord Beaconsfield considered that the demand for chemicals was a better test as to the state of trade.

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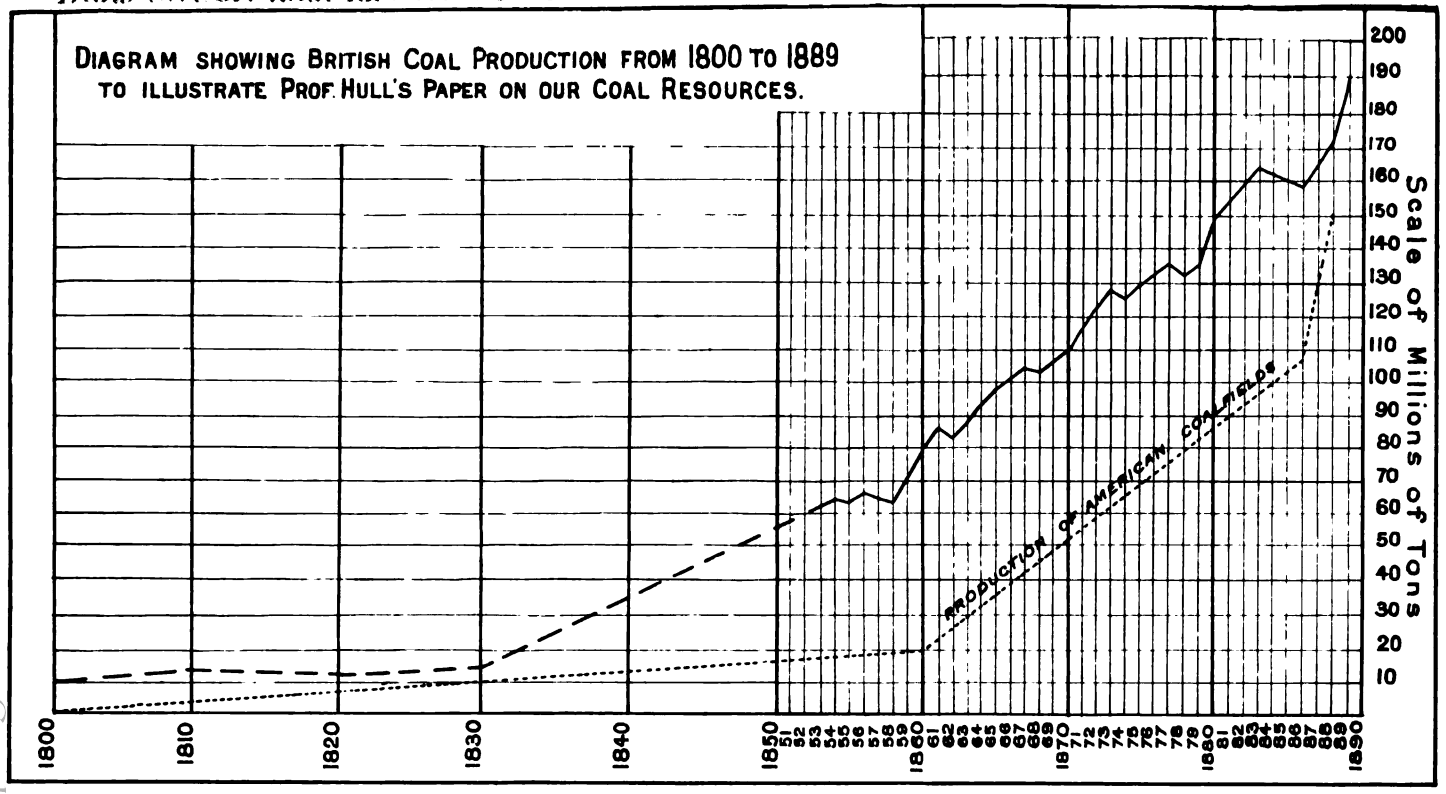

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(*a*) *Progressive Coal Fields.*

1. South Wales and Monmouthshire.
2. Bristol and Somerset (slightly progressive).
3. Denbighshire (slightly).
4. South Stafford and Worcestershire.
5. North Staffordshire (slightly).
6. Lancashire and Cheshire.
7. Cumberland.
8. Warwickshire.
9. Derbyshire, Notts, and Yorkshire.
10. Northumberland and Durham.
11. Scotland.

(*b*) *Stationary or Retrogressive.*

1. Forest of Dean (Gloucestershire).
2. Coalbrook Dale (Shropshire).
3. Flintshire.
4. Leicestershire.

A few observations on the above may here be added.

a. South Wales and Monmouthshire.—The increase of coal production in this great coal basin has been very remarkable. In the quarter of a century between 1854 and 1879, it had doubled its production, which in the year 1888 had reached 27,355,250 tons. This is largely due to the great demand for steam coal from the Cardiff district, for use both at the home and foreign naval stations. The resources of this coal basin are enormous, and render it capable of maintaining or increasing its present output for a long period of years. Several deep collieries have recently been opened out.

b. The Bristol and Somerset Coal Field, which is largely concealed under secondary strata, maintains a slightly progressive position with occasional fluctuations. Between 1887 and 1888 the output made a considerable advance, and in the latter year reached 1,422,600 tons.

c. The output from the *Forest of Dean and Coalbrook Dale Fields* is stationary or retrogressive. In the latter case much of the coal has been worked out, and (as I am informed by Mr Wynne, formerly the Inspector of Mines for that district) several collieries have recently been closed owing to the accumulation of water in the working, and the exhaustion of the coal. It is only at Lilleshall that extensive business is being carried on.

The Denbighshire Coal Field has several valuable seams which may be worked for long distances under the upper coal measures and the Permian formation. Though making progress as a coal-producing district, this is not as rapid as might have been ex-

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pected. The quantity raised in 1888, namely, 2,061,488 tons, was but slightly in excess of that of the previous year.

Flintshire.—On the other hand the Flintshire Coal Field is stationary or retrogressive, and the output small. The coal has been very largely worked out and is much faulted; but there are considerable tracts of the New Red Sandstone and Permian areas lying to the westward of the coal field under which the seams will one day be mined.

The South Stafford and Worcestershire field is one of great interest, from the fact that it contains the thickest seam of coal in the British Isles. This seam of ten yards has been largely worked out in the Dudley district, and in other parts flooded by water; but in the northern part of the district, about Cannock, there is still a large reserve of coal, and this is being worked underneath the New Red Conglemente and Permian formations, both at Cannock Chase and at Sandwell near Birmingham. The production is increasing, if we take the whole district, but locally is decreasing from exhaustion of the mines. Mr W. B. Scott writes hopefully of the future of this coal field on the recurrence of prosperity in the iron trade.

North Staffordshire.—The increase in production has not been as rapid in North Staffordshire as the resources in this district, both in coal and in iron, might lead us to expect; in fact, during the last ten years the production in coal has been very little removed from stationary, and is only half that of South Staffordshire. Yet it may be safely affirmed that the resources of the former are fourfold those of the latter, and that as a coal-producing district it will long survive its rival in the southern part of the county.[1]

South Lancashire and Cheshire.—The increase of production of coal in the South Lancashire coal field has been exceedingly rapid within the last quarter of a century, owing to the extraordinary commercial and manufacturing activity of the county palatine; and it is worthy of remark that this activity is but very slightly connected with the iron trade. The demand for coal is largely due, not only to local consumption, but to the export trade to almost all parts of the world, including France, Spain and Portugal, Italy, the Mediterranean ports, East and West Indies, and North and South America. Ireland, and especially the city of Dublin, receives large supplies from the Wigan district.

Derbyshire, Notts, and Yorkshire.—The great coal field of Notts, Derbyshire, and Yorkshire is remarkably progressive,

[1] In "The Coal-Fields of Great Britain," 4th edition, I have given the quantity of coal in North Staffordshire as 3,680,000,000 tons, and that of South Staffordshire as 900,000,000 tons.

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and sends large supplies not only to the great manufacturing districts of the immediate neighbourhood, but to the metropolis. Between 1860 and 1885 it had doubled its production, which is now about thirty-six millions of tons. Coal-mining is in this district advancing eastwards into the large tracts overlain by the Magnesian Limestone and New Red Sandstone.

Northumberland and Durham.—The great northern coal field of Northumberland and Durham shows no sign of falling off in its output of coal, notwithstanding the long period through which coal-mining has been carried on, and the great export trade from the Tyne. The discovery of Liassic iron-ore in the Cleveland district, and the consequent establishments of large smelting and manufacturing works along the valley of the Tees, has given a great impulse to mining within the last quarter of a century; and the export trade from Newcastle, Shields, Sunderland, and Hartlepool accounts for about one-third of the entire produce, which in 1888 amounted to 22,319,104 tons. The enormous drain on the resources of this coal-field, of which the limits beneath the Permian formation have been pretty definitely determined, cannot fail to cause a serious falling off in the output during the twentieth century, although there is sufficient coal still remaining to meet the present demand for about 300 years.

The southern limit of the coal-field under the New Red Sandstone and Magnesian Limestone may be inferred to stretch westward from Hartlepool till it emerges near Staindrop.[1] A boring recently carried down to a depth of 1814 feet near Seaton-Carew by Mr W. J. Bird, M.E., had to be abandoned in coal measure before any important seam of coal had been proved.[2] Castle Eden Colliery is situated about four miles to the north of the concealed southern limit.

Scotland.—The production of the coal-fields of Scotland show a continuous increase for many years past in keeping with the great strides made by that part of the United Kingdom in manufacturing industries. From their isolated position the Scotch coal districts are less open to successful competition from other coal producing districts than some of those in England and Wales. Hence the coal required for iron-smelting and forging, for manufacturing and household purposes is drawn mainly from the immediate place of production; while large quantities are exported to Ireland and foreign parts, from the adjoining ports of Leith, Granton, Borrowstounness, Kirkcaldy, Glasgow, Troon, and

[1] The position of this southern limit is shown on the map accompanying the description of the Durham coal field in the 4th edition of "The Coal-Fields of Great Britain," p. 272.

[2] "Trans. Geol. Soc., Manchester," vol. xlx.. p. 564; and *ibid.*, vol. lxx. p. 263.

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Ayr. The coal-fields of Scotland have doubtless a prolonged future before them; but, being all devoid of any protection from the overspread of Secondary formations, their limits and ultimate contents can be absolutely determined, and there is no margin for possible theoretical extension, as in the case of some of the English coal-fields.

Having thus passed in review the progress of coal-mining in all the chief centres of production, and determined the ratio between the output and resources, the questions remain for consideration, Do our natural coal stores show any symptoms of exhaustion? and What are the prospects of coal-mining in the *near* future?

From the statements and estimates which have been presented it seems to me that the conclusion may fairly be gathered that failure of our coal supply to any appreciable extent in the near future is not to be expected, but that there will be a tendency towards a rise in the price of coal itself may be regarded as certain.

This rise in the money value of coal will be due, not to any appreciable diminution in the available quantity of coal, but to the increase of expense in mining consequent on the greater depth at which coal must generally be worked as time goes on. As the shallow pits are being worked out, and the shallow coal seams become exhausted, deeper pits will become a necessity, requiring larger outlay of capital, more expensive machinery and appliances for raising the coal,[1] and increase of miners' wages. All these and other items of increased expense must of course come to be defrayed by the consumer; and I look upon it as tolerably certain that within the next half-century there will occur a general rise in the price of coal throughout the British Islands. This rise, if it will not tend to check consumption, will at any rate have the effect of checking waste and extravagance in the use of this precious natural commodity. The general rise in the price of coal would probably have taken place ere this if it had not been for the rush which the prosperous years between 1880-83 caused into the coal trade, and the large number of new collieries which were commenced, and which when commenced, had to be completed and worked. The consequence of this was the excess of production over demand during the years 1883-86, and a lowering of prices which left a very small margin of profit in the case of the better class of collieries, and caused positive loss in those not so favourably situated. The

[1] At the present time coal is being worked in Lancashire and Cheshire at a depth of about 3000 feet from the surface; and shafts have been sunk to depths of 700, 800, and 900 yards for winning coal. By the end of this century such depths will not be unusual.

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demand has again risen, and it is to be feared that in the case of coal-mining as of other events, "history will repeat itself," and coal-mining will be overdone.

As regards the more distant future, I am not one of those who imagine that as a source of power and motion coal can be replaced by some other agent. As the late Professor Jevons has truly said: "Coal stands not beside, but entirely above all other commodities. It is the material energy of the country, the universal aid, the factor of everything we do. *With* coal almost any feat is possible or easy; *without* coal we are thrown back into the laborious poverty of early times." Let us therefore husband our resources, let us avoid waste, and turn to the maximum of use the minimum of fossil-fuel which is of more value to us than the gold of Ophir.

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XI.—*Notes on the Coal Question (with Diagram).* By H. M. CADELL of Grange, B.Sc., F.R.S.E., *Hon. Secretary.*

(Read 16th January 1890.)

PROFESSOR HULL'S important paper on "Our Coal Resources" opens up for discussion a question which has at the present time a peculiar interest, and is likely ere long to attract a still larger amount of public attention.

This truly *burning* question is many-sided, and may be discussed from a great variety of stand-points. At present the economic aspect of the question is perhaps the most important, as coal has lately advanced considerably in price, and the newspapers have been full of accounts of labour disputes and strikes, all more or less directly connected with the coal industry. I have lately had occasion to look over some lists of the prices of coal shipped for household purposes at the Firth of Forth ports within the last fifty years, and I find that, except during the years 1872 and 1873, when coal rose to an altogether abnormal height, the present prices are the highest that have been reached during this half century. The fluctuations are exhibited graphically on the accompanying diagram, which shows the selling price at the end of each year from 1839 to 1889.

Now this state of matters naturally demands some explanation; and, if it be an evil, we are as naturally driven to look about for a remedy.

1. *As to the cause.* When our coal supply begins, as it will one day do, to show signs of running done, prices will as certainly begin to rise till they reach the height at which it will pay foreigners to send us coal from less exhausted fields. This, however, was not the cause of the coal famine in 1872-3, and Professor Hull's paper shows clearly that the present century at least will see no diminution on the score of natural exhaustion of our carboniferous deposits. The output has, on the whole, increased tolerably uniformly since the second decade of the century, notwithstanding the great fluctuations in price. It is tolerably clear that the rise in production at any particular period above the normal rate is caused by the rise in prices, and the cause of the stagnation at particular times is distinctly due to a decline in prices caused by over-production and a glutted market. A certain definitely increasing quantity of coal is required, and if this quantity is not supplied, prices will of course rise. The present rise in prices seems to be due to a reaction after the period of dulness that came to an end in 1888, when coal fell to a price as low as in 1869, just before the great boom

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in the trade began. The large stocks of coal which had accumulated during the dull years have been worked off to a great extent, and this, together with the restrictive policy of the miners, has tended to retard production, so that prices have begun to rise. If the prospect of a revival in trade leads speculators to rush in and again glut the market, there will be a consequent fall in prices, as there was after the last great boom had reached its climax. The present increase in the price of iron is due, partly at least, to the rise in the cost of fuel to smelt it; and, of course, all other branches of industry must be similarly affected.

A great proportion of the extra price of the coal goes to the miners, who, in some parts of Scotland, have had their wages advanced between 60 and 70 per cent. since the autumn of 1889. They are at present one of the richest of the working classes, as they can earn from 7s. to 10s. or more, within a short working day of eight hours. While their incomes exceed those of many professional men, their domestic requirements are very much smaller, and the cost of food is very low. Now is their opportunity for saving if they will but seize it. But, alas! I am afraid that the money will go in most cases as easily as it has come, and we shall see a repetition of the extravagance and waste that accompanied the "good times" in '73.

2. *As to the Remedy.*—Apart altogether from any interest in coal-mining, I think, on purely economic grounds, that, broadly speaking, a considerable rise in the price of our precious fuel is in the long run a great benefit to the community. For the last ten years coal has, I cannot but think, been far too cheap, and in consequence vast quantities have been wasted both by the producer and the consumer. It may seem paradoxical to say that the producer wastes his coal, but it is nevertheless quite true. In every coal field there are both thick and thin seams. The thin seams do not pay to work unless the prices are good, and the thick seams in some cases cannot be entirely extracted, and part of the coal is left in to form a "roof" or "pavement" to the workings as the case may be. When all the best coal has thus been plundered, and perhaps a third or half left in, the coal-field is regarded as exhausted, and is abandoned and allowed to fill with water. It would never pay as a general rule to reopen such a coal-field for the sake of the residuum of coal left in; but if the prices had been remunerative while it was in operation, the whole might have been extracted with advantage, and no hidden wealth left which future generations may know of but cannot reach. Another advantage of dear coal is that it tends to turn the public mind to methods of economising fuel, and I have no doubt that this year will produce a plentiful crop

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of patent stoves and other useful appliances by which the greatest efficiency may be obtained at the smallest cost. A vast quantity of coal is wasted in every household simply because it has of late years not been worth our while to think of saving it.

As to the ultimate exhaustion of our coal fields, I am not one of those who have any evil apprehensions. The process will be an asymptotical one, and when signs of a general decline in the output from this cause appear, and a consequent permanent rise in prices begins to set in, people will bestir themselves to invent still more economical heating and lighting appliances. The vast volumes of combustible gases and unconsumed carbon that issue from our chimneys will cease to contaminate the air. House-maids will not throw out good cinders with their ashes, and Highlandmen will pay more attention to their peat mosses, which in some districts are being left unused because peat is dearer than coal from the land of the Sassenach.

If the coal is to fail in, say six hundred years, it will pay the large highland lairds or whoever may have the land, to start five hundred years after this and plant trees, which a century or so later may be cut and sold for fuel to the rich people of the south. The waterfalls may be also utilised to drive dynamos or keep the railways going in summer by electricity. The tides and the winds, although at present regarded as unsatisfactory sources of energy, may also be turned to good account. These may be used, I do not mean to say as a *substitute* for coal, but as a colleague, so to speak, to King Coal when he begins to grow feeble. When our coal fields approach exhaustion at workable depths we shall, of course, begin to import, with the money our ancestors have obtained by exporting. But in the meantime we should begin to economise so as to put the evil day as far off as possible, and unless human nature grows remarkably wise all of a sudden, we shall never learn economy unless compelled by high prices to do so.

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XII.—*Observations on the Geology of a part of the Puy de Dôme district of France.* By RALPH RICHARDSON, F.R.S.E., W.S., *Hon. Mem. Lit. and Phil. Soc., St Andrews; Vice-President.*

(Read 20th February 1890.)

LAST summer I paid a visit to a classical geological field. This was the Department of Puy de Dôme in Central France, a district specially studied by Lyell and Murchison, and splendidly explained by Mr G. Poulett Scrope, M.P., F.R.S., in his great work on "The Geology and Extinct Volcanoes of Central France," a second edition of which was published in 1858. The interest of that district consists in its containing the remains of numerous subaerial volcanoes of comparatively recent geological age.

No doubt, we have in our own immediate vicinity, in Arthur's Seat, the remains of an ancient volcano, but that was a submarine volcano, and not only so, but a volcano eventually covered with a vast accumulation of stratified rocks which have been removed by denudation.[1] In the case of the volcanoes of the Puy de Dôme, on the other hand, although they doubtless have suffered much subaerial denudation, yet sufficient remains of their general features to display to us to-day what they have been from the commencement, and to enable us to realise that throughout Auvergne, the province in which the Department of Puy de Dôme is situated, great subaerial volcanoes existed, spreading in every direction the evidences of volcanic action on the grandest scale.

With regard to the antiquity of the volcanoes of the Puy de Dôme district, Scrope states, after a minute examination, that "nothing like an approximation to a knowledge of their positive ages can be expected, however interesting the elucidation of this question would be. All we know is that, in spite of the very fresh aspect of many of them, their production must have been anterior to the earliest historical records of this locality, in which no mention is found of any volcanic eruptions."[2] We have however, thanks to fossil remains, a clue to the age of at least a part of the volcanic history of this district, for on the road between Beaumont and Ceyrat, near the chapel, a section occurs showing the lava of Gravenoire overflowing diluvium which is believed to be contemporaneous with that found in the caves of Vezère, which were inhabited by the hunters of reindeer.[3] If this be true, then the volcanic eruptions must, at

[1] Well described in *Scotsman* of 23rd September 1889.
[2] "Volcanoes of Central France," 2nd ed., 1858, p. 45.
[3] The Royat Guide Book (in English), published at Clermont-Ferrand.

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least in their later stages, have extended into the human period and have probably driven from their caves the hunters of the reindeer and mammoth.[1] Sir Charles Lyell, in his "Antiquity of Man,"[2] describes the caverns of the Dordogne, a river which rises in Puy de Dôme, and of which the Vezère, already mentioned, is a tributary. He visited the caves in 1872, and found them like Kent's Cavern near Torquay, and full of human and animal remains. The most remarkable discovery made in these Dordogne caves was perhaps the carving in ivory (so often reproduced in text-books), representing the mammoth with its long hair and huge curving tusks, carved by a prehistoric artist, and forming one of the earliest designs executed by the hand of man.

If we accept the view that a lava-flow covers diluvium contemporaneous with these caves, we arrive at the conclusion that the volcanoes of the Puy de Dôme district come down to a very recent geological period. A "granitic platform," as Scrope calls it, is the base-rock of the district, and through it has frequently welled forth basalt which often forms beautiful columnar ridges. Some of these basaltic currents occurred during an ancient, and some during a recent, volcanic epoch. It is evident, therefore, that the geology of this district attests a long era of volcanic energy, during which the whole face of the country has been transformed: basalt-columns, lava-flows, and ash covering it in every direction. I propose to refer only to that portion of the district near Royat, the well-known watering-place close to Clermont-Ferrand, the capital of the Department of Puy de Dôme. I made several excursions from that convenient centre, and ascended the Puy de Pariou (4012 feet above the sea), and also the mountain from which the department takes its name, the remarkable Puy de Dôme (4842 feet high). Perhaps I cannot do better than describe the geological phenomena observed during these ascents.

Leaving Royat and ascending the valley of the little river, the Tiretaine, to the hamlet of Fontanas, we note that volcanic rocks are on every hand. The granitic base-rock frequently appears, but the more recent rocks are also seen. Lava from the now extinct volcanoes to the west had flowed down this valley, seeking the line of least resistance and obeying the law of gravity, just as a glacier would have done, and just as the Tiretaine river does to-day. Arrived at the summit of the valley, we breathe a purer air and observe a grand panorama of

[1] In connection with this subject, I did not observe any traces of glaciation in this district. Nor did Dr Black, another member of our Society, who preceded me, and more narrowly examined it.

[2] 4th ed., 1873, p. 134.

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the mountains. To the left, towering above all, is the massive bell-shaped Puy de Dôme, the glory of the locality. To its right, and 655 feet below it, is the so-called Petit Puy de Dôme. Still to the right is the Puy du Petit Suchet (3983 feet high). Finally, still further to the right, is a mountain having apparently a volcanic cone on its top. This is the Puy de Pariou (4012 feet), an ancient volcano—the apparent cone however being not a cone but the corner of the old crater jutting at this point against the sky-line and forming a conical peak.

We have now reached one of those magnificent highways which traverse France and were once called "Routes Imperiales," now "Nationales." Turning, however, to the left, not far from the village of La Baraque, we drive to the base of the Puy de Pariou, where we find an artillery camp, gun practice being carried on here along a range of 3000 yards which stretches as far as the Puy de Dôme mountain. A vast lava field called the "Cheire de Pariou" extends round this side of the Puy de Pariou; and we can still note, as on the sides of Vesuvius, how, like a fiery flood, the lava had once streamed forth and leapt curling and twisting down from the crater to the valley, its surface still bearing the appearance of a black serpentine torrent, viscid of texture and bubbling with heat.

The ascent of the Puy de Pariou is best made by following a lava-flow up the mountain side. It is a steep ascent, and in a glaring sun a trying one. However, it well repays the labour, for, after a certain height is reached, the view of a vast empty crater bursts upon us and presents a spectacle which probably we never beheld before. The crater's grassy sides are perfectly smooth, and descend abruptly 300 feet to the bottom of the crater. Its circumference is enormous, 3000 feet. We now find that the whole top of the hill has been hollowed out, and that what we formerly thought was a volcanic cone is only the extreme highest end of the crater. Scoriae lie on the surface of the ground, whilst, from the summit, volcanic hills are seen on every side, notably the Puys de Fraisse, de Come, de Clierson, and du Grand Suchet. "Puy" is the local name for a volcanic hill.

In his "Manual of Geology"[1] Lyell refers to the Puy de Pariou as follows:—"The brim of the crater of the Puy de Pariou, near Clermont, is so sharp and has been so little blunted by time, that it scarcely affords room to stand upon. This and other cones in an equally remarkable state of integrity have stood, I conceive, uninjured, not *in spite* of their loose porous nature, as might at first be naturally supposed, but in consequence of it. No rills can collect where all the rain is instantly absorbed

[1] 5th ed., 1855, p. 556.

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by the sand and scoriae, as is remarkably the case on Etna." He therefore holds that even the freshest looking cones may lay claim to very high antiquity. Dr Daubeny points out that had any of these volcanoes been in a state of activity in the age of Julius Cæsar, that general, who encamped upon the plains of Auvergne and laid siege to its principal city (Gergovia, near Clermont), could hardly have failed to notice them. Further, Pliny made no reference to eruptions here in his Natural History; whilst the poet Sidonius Apollinaris, a native of Auvergne, actually resided here on the banks of Lake Aidat, which owed its very existence to the damming up of a river by one of the most modern lava currents.[1] It would seem therefore that, although the pre-historic cave-hunters saw the volcanoes in eruption here, the much later Romans did not.

Scrope considers "from its aspect, and that of its lava," that the Puy de Pariou "may be supposed the product of one of the last eruptions which convulsed the country. It is also one of the most considerable and regular cones of the chain."[2]

I now proceed to the Puy de Dôme mountain, which, I would observe, is not a volcanic cone or crater of eruption, but is a mass of a variety of trachyte called after it *Domite*. This mountain rises 4842 feet above the sea, and about 1600 feet above its base, the sides sloping at an angle of from 30° to 60.°[3] A good road has been made to the summit, on which stand a meteorological observatory and the ruins of a vast temple erected by the Romans to Mercury Arvernus[4] which Gregoire de Tours states was destroyed by Chrocus, king of the Germans, who ravaged Auvergne in the third century after Christ. A vitrified fragment of the domite caused by the burning of this temple is in the Museum of Clermont-Ferrand.

The ascent of the Puy de Dôme from Royat follows the road to Fontanas, thereafter continuing straight to the base of the mountain along prettily wooded slopes. A quarry of kaolin is passed at the foot of the mountain. The base-rock of the volcanic region here is partly composed of gneiss and partly of "veined granite, in which transitions from a coarse to an extremely fine grain are very frequent."[5] The kaolin is decomposed gneiss. "Near Limoges and St Yrieix the gneiss rock is decomposed into a kaolin of great purity, which has long supplied the

[1] Daubeny on Volcanoes, p. 14; Scrope, op. cit., p. 92.
[2] Op. cit., p. 61.
[3] Ibid., p. 45.
[4] Cæsar says that Mercury was the principal deity of the Gauls, in whose honour they erected numerous statues: so this temple may perhaps occupy the site of a Gallic sanctuary.
[5] Scrope, op. cit., p. 41.

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china factories of Sèvres and Paris, and is even exported to the United States."[1]

The once toilsome ascent of the Puy de Dôme mountain can now be accomplished in the easiest way. A tandem dogcart following a fair mountain road up very steep inclines soon transports tourists to the summit. From hence a magnificent view extends in every direction. Beneath us to the east lies Royat, embowered in its deep foliage-clad valley; whilst beyond stretches the twin city of Clermont-Ferrand on the River Allier, which flows through the fertile Limagne. To the west we see the wilder country, which includes the mountains and forests of Mazayes and Pontgibaud. To the north and to the south extends a long line of extinct volcanoes, their empty craters and smooth sides giving them the appearance of a number of felt hats with the tops slightly crushed in. The Puy de Dôme stands towering in the midst of this line of volcanoes, a line which extends to no less than thirty English miles.

As I have already mentioned, the Puy de Dôme mountain was never a volcanic cone of eruption, but is a mass of igneous rock, a variety of trachyte termed domite. It is not the only domitic hill here, for to the north of it the Puy Chopine, Le Grand Sarcoui, Clierson, and Le Petit Suchet, are all composed of masses of domite. Now, how were these masses upreared and these mountains formed? That is one of the geological enigmas and battlegrounds of the Puy de Dôme. Some, like Desmarest, thought that domite represents a granite calcined *in situ* by a volcanic conflagration around it. Others, like Saussure, that it is a petrosilex which has undergone the same operation. Others, like Dolomieu, Mossier, Montlosier, and Du Buch, thought that domite is a granite triturated or liquefied by volcanic agency below the earth and then by a sudden expansion of gas propelled through different apertures, over which it was consolidated in the form of huge bubbles.

Scrope accepts none of these theories, but considers that this domite of the Puy de Dôme chain, being composed wholly of felspar and therefore possessing the lowest possible specific gravity, and at the same time a very rude and coarse grain and highly porous structure, is precisely that species of lava which we should expect, *a priori*, to have possessed the minimum of fluidity when protruded into the air; and he says we can therefore understand why, instead of flowing in thin and continuous sheets or streams to a distance from its vent, like the basaltic lavas produced about the same time and from the same fissure, it has accumulated in dome and bell-shaped hillocks on the point where it was emitted. Scrope is the more

[1] Scrope, op. cit., p. 3.

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satisfied that this theory is the correct one from the fact that these masses of domite were evidently thrown up on the spots they now occupy, seeing that they, in every instance, rise either from the middle or the side of a regular crater and cone of scoriae.[1]

With reference to this theory advanced by Scrope, Dr Archibald Geikie points out in his text-book,[2] that Von Seebach has distinguished two volcanic types, viz., 1st. *Bedded Volcanoes*, composed of successive sheets of lavas and tuffs, and embracing the great majority of volcanoes; and 2nd. *Dome Volcanoes* (such as the Puy de Dôme mountain), composed of homogeneous protrusions of lava without fragmentary materials, craters, or chimneys. Von Seebach thought the same volcano might, at different periods, belong to one or other of these types, according to the nature of the lava erupted—the lava of the Dome Volcano stage being less fusible and more viscid than that in the Bedded Volcano stage. Dr Geikie, however, reminds us of the power of denudation, and points out that the mere absence of ashes and scoriæ is no proof that these did not once exist, or that the present knob or boss of lava may not originally have solidified within a cone of tuff which has been subsequently removed in denudation. In other words, whilst admitting generally that the theory of Scrope and Von Seebach, as regards the formation of dome volcanoes (such as the Puy de Dôme mountain) may be in some cases correct, Dr Geikie doubts whether a large proportion of the examples cited from the Rhine, Bohemia, Hungary, and other regions ought not rather to be regarded as the remaining roots of true volcanic cones, like the "necks" so abundant in the ancient volcanic districts of Britain.

If Scrope's theory be correct, as to the origin of the Puy de Dôme mountain, we can imagine an outburst of lava taking place from the neighbouring craters of the Puys de Besace and de Gromanaux, and, for the reasons already stated, instead of flowing down to a distance from the vent in continuous, thin streams, accumulating in the bell-shaped form which we now see in the Puy de Dôme mountain. Cliffs of trachytic lava still environ the craters of the two Puys just named. As to the crater of the adjoining Petit Puy de Dôme (called Le Nid de la Poule or "Hen's nest"), its materials are entirely different, being composed not of trachyte but of fragmentary matter, basaltic scoriæ, sand and ashes. From the western base of the Petit Puy de Dôme a stream of basaltic lava poured over the

[1] Op. cit., p. 50.
[2] 1892, p. 243, note, and p. 255.

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granitic platform[1] to a distance of over five English miles, and covered an area a mile in breadth.

In conclusion, let us attempt to arrange in chronological sequence, the strange geological events which have occurred in this district.

First of all, we find a country composed of a granitic or gneissose plateau indicative of very ancient rocks indeed. Currents of basaltic lava mark the opening of volcanic action.

Secondly, during a comparatively recent geological period, volcanic action set in again. This showed itself prominently in two ways, viz., first, in the welling-up of trachytic lavas which formed the so-called Domitic Mountains; and secondly, in the production of ordinary volcanic cones and craters of eruption, from whence poured streams of basaltic lava to a great distance, accompanied by showers of ash now forming deep deposits.

In the *third* place, during the epoch of the pre-historic cave-hunters of the mammoth and reindeer, an eruption occurred, the lava of which covered diluvium contemporaneous with human caves.

In the *last* place, during the Roman occupation of the country, volcanic eruptions were unknown, and from that period till now no volcanic activity has been apparent.

Specimens of Rocks Exhibited.

1. Granite, the base-rock of the Puy de Dôme district, obtained near Royat.
2. Compact Lava, from the Cheire or Lavafield, formed from the Puy de Pariou volcano.
3. Cellular Lava, from the said Cheire.
4. Scoria from the crater of the Puy de Pariou.
5. Scoria from the top of the Puy de Dôme mountain, whither it had been blown from perhaps the crater of the Petit Puy de Dôme, the so-called Nid de la Poule, or "Hen's nest."
6. Domite (Trachyte) from the Temple of Minerva on the summit of the Puy de Dôme mountain.
7. Domite (Trachyte) from further down said mountain.
8. Kaolin from the base of said mountain.
9. Lava which once flowed down the valley of the Tiretaine river towards Royat.

[1] Op. cit., p. 55.

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XIII.—*Dolomitic Limestones.* (*Abstract.*) By J. G. GOODCHILD, H.M. Geological Survey, F.G.S., *Lecturer on Geology and Palæontology at the Heriot-Watt College.*

(Read 20th February 1890.)

DOLOMITIC LIMESTONES may have been formed in any one of many different ways. Some of these were noticed in detail. Amongst those of *primary* origin were (1) the various modes of precipitation connected with the deposition of strata of lacustrine origin formed in closed bodies of inland water where supply is balanced by evaporation. The materials are derived (amongst other sources) from the decomposition of the ferro-magnesian silicates. (2) Precipitation consequent upon (*a*) the dessication of lagoons, or other temporary inlets of sea water; or (*b*) upon the mingling of various solutions. (3) Deposition direct from percolating solutions derived from the decomposition of basic igneous rocks situated at higher levels. Much of this is deposited as pearl spar in veins or other fissures, but occasionally masses of more importance are formed in this way. (4) Calcareo-magnesian matters exuded in consequence of the alteration of rock-forming silicates undergoing plutonic metamorphism, are, again, another source of certain dolomites of limited horizontal extent. (5) Some dolomitic limestones may, possibly, have originated directly through the secretion of small quantities of carbonate of magnesia, along with carbonate of lime, by various organic agencies.

Dolomites of *secondary* origin have nearly all arisen through the addition of magnesian salts—usually the carbonate—to limestones already existing as such. In some cases, as in that of The Magnesian Limestone, the rock may have been of lagoon origin, and therefore partly a magnesian precipitate, to begin with, and have subsequently received a further addition of magnesian matter through the copious downward percolations coming from the chief repository of such salts, the marls and sandstones of the "Upper New Red." In the great majority of cases dolomites of secondary origin have originated through the alteration and the partial replacement of calcareous matter —originally free from magnesian salts—through the downward percolation of solutions containing magnesia in one or other of its forms originally deposited in connection with other rocks at a higher level. In a few cases this higher-lying source of magnesian solutions is an igneous rock of basic composition undergoing weathering. But in the great majority of cases, the direct source of the magnesian matter is one or other of the

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Red Rocks—New Red, Old Red, or any other mass of strata formed in close bodies of inland water. (Even in such cases, of course, the original source of the material is traceable to the decomposition of the ferro-magnesian silicates.) As a good example of the kind of alteration referred to may be cited the limestones of the Carboniferous rocks, where they are yet, or have formerly been, covered by the New Red. From the Red Rocks referred to, magnesian solutions (always accompanied by ferruginous salts) have percolated downward into the rock beneath, staining the sandstones, and even the shales, and at the same time altering the limestones in some cases to an extraordinary extent. The solutions find their way downward along any divisional plane—joints, bedding planes, faults, &c.; and thence, extending into, and partly replacing, the calcareous matter adjoining, they convert this into friable, granular dolomite. The diminution in bulk consequent upon the addition of carbonate of magnesia to carbonate of lime brings about a general contraction of the part of the rock affected, whereby the texture of the rock is altered from compact to loose, while joints and other divisional planes are stretched wider open; and, more important still, geodes, drusy cavities, and a general cellular structure, are set up in the parts of the rock within the influence of the solutions that cause the contraction. It is this factor that has had much to do with the rearrangement of the Magnesian Limestone itself. The superaddition of magnesian matter to a limestone already partly magnesian in origin has brought about a diminution in bulk; and this, taking place while the constituents of the rock were comparatively free to change positions amongst themselves, has led to the formation of botryoidal structure, such as that seen in the Sunderland cliffs; or to the development of the equally-remarkable cellular structure seen at so many other localities.

Reasoning back from effects to causes, one may infer from the presence of the above-noticed alteration structures in the limestone, &c., of the Carboniferous rocks, that the staining and alteration of the shales and sandstones, and the dolomitization of the limestones, point to the former extension of the New Red Rocks over the rocks so affected. The writer mentioned, when this paper was read, that large areas of the Carboniferous rocks of the Basin of the Forth exhibit these features characteristic of infiltration from the New Red. This is especially the case with the Carboniferous rocks of the Dalkeith coal field. The sandstones and the shales are irregularly stained, while the limestones, with equal irregularity, are more or less dolomitized. From this the writer would draw the conclusion that the New Red Rocks have formerly covered those parts (and the areas

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adjoining), and that their final disappearance there has taken place within geological times quite recent; if, indeed, remnants, concealed beneath the drift, do not exist even yet.

As the New Red Rocks bear the same geological relation to the Jurassic Rocks that the Upper Old Red does to the Carboniferous, it would follow from this conclusion that the writer believes that the Jurassic Rocks, also, formerly extended over the Lothian area, and the south of Scotland generally.

In conclusion, the writer pointed out that the replacement of calcareous matter by dolomite was one of the first steps towards the complete replacement of the calcareous matter by *hæmatite*, which, like the magnesian matter itself, was imported into the rock affected by means of downward percolations from the New Red. Both the iron and the magnesia being thus derived primarily from the decomposition of ferro-magnesian silicates, the concentration of the solution by evaporation in closed bodies of inland water, their location for a time in the lacustrine sedimentary rocks, and their final transference, through downward filtration, led to their present lodgment in the calcareous rocks below.

Some reference was also made to the dolomitization consequent upon volcanic and other action.

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XIV.—*The Composition and Origin of the Rock Dolomite.* By Alexander Johnstone, F.G.S.

(Read 20th February 1890.)

This paper considers briefly the question of the origin of the rock dolomite, which has long been regarded as a standing enigma in our science. In order to deal with the subject in as concise a manner as possible, I will first give—from my standpoint, of course—a brief account of the composition, mode of occurrence, and nature of association of the rock, and then conclude with the very simple theory which I have been tempted to construct from the results afforded me by some experimental researches.

The Composition and Constitution of the Rock Dolomite.—In I should say all of the accepted chemical and petrological treatises, even of the most recent date, the statement invariably occurs that the rock dolomite is a *double* carbonate of calcium (or lime) and magnesium. The seriousness with which this assertion is constantly made, is all the more astonishing when we recollect that the results of all the numerous trustworthy analyses that have been made for the last eighty years are quite antagonistic to it.

The well-known dolomite of Faxoe, which was repeatedly analysed by Forchhammer, gave in one sample 97·13 per cent. of carbonate of lime, and 2·87 per cent. of carbonate of magnesia; and in another, 53·38 per cent. of the former, and 41·41 per cent. of the latter salt, and the results of the other analyses were equally divergent. Here, then, a series of very careful analyses by a highly competent man shows how wide a difference exists in quantitive composition between naturally contiguous, or nearly contiguous, specimens of the same dolomitic mass. Karsten found the opposite ends of one piece of dolomite composed as follows:—

	I.	II.
Carbonate of lime, ...	63·27 per cent.	57·75 per cent.
Carbonate of magnesia,	35·97 „	41·32 „

Bischoff found two specimens of magnesian limestone from Stadtbergen to have the following composition:—

	A	B
Carbonate of lime, ...	98·22 per cent.	84·57 per cent.
Carbonate of magnesia,	1·32 „	11·54 „

Iron, silica, and carbon make up the 100 per cent. in each case.

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Three analyses of the dolomite of Durham by myself gave :—

	I. per cent.	II. per cent.	III. per cent.
Carbonate of lime, ...	65·32	83·05	90· 0
Carbonate of magnesia, ...	30·68	11·16	3·99
Impurities (iron, carbonic acid, clay, silica, &c.), ...	4·00	6·79	6·11
	100·00	101·00	100·10

All these results I consider completely disprove the assertion of the books. If the rock dolomite were a double carbonate of calcium and magnesium it would invariably give 54·35 per cent. of calcium carbonate, and 45·65 per cent. of magnesium carbonate, or figures exactly proportionate to these. But it does not, and seeing that this is the case, that no two analyses of the rock are alike, then it appears to me to be plainly evident that the two carbonates are merely in a condition of simple mechanical mixture, and not at all as generally believed in a state of chemical combination.

Kinds of Dolomite.—There are two varieties of the rock dolomite. The typical, and by far the most abundant sort, is usually more or less coarsely or finely crystalline or compact. Its origin will be considered in this paper. The other variety is clearly metamorphic in nature, and is found in irregular bands traversing common limestone, which in itself may either be in an altered or practically unaltered condition. The latter kind of dolomitic rock has undoubtedly been produced by the influence of percolating water carrying magnesia salts in solution, and as all the facts go to show that such has been the case of the formation of this type, it will not, I think, be needful to take any further notice of it here.

The Occurrence and Paragenesis of Dolomite Rock. — The typical form of massive dolomite, *i.e.*, the form which is evidently in its original state and has not been produced by metamorphic action, is only found in any quantity in the company of undoubtedly marine or salt-lake strata. All the fresh water formations with which we are acquainted appear to contain either exceedingly little or absolutely none of it. Dolomite occurs either in fairly regular beds, or in irregular lenticular masses. It is occasionally fossiliferous, but is perhaps more often entirely barren of organic remains. The fossils which do occur in it are always relics of purely marine or salt water animals and plants.

The Origin of the Rock Dolomite.—I now come to attack with some diffidence the problem of the origin of typical dolomite. Microscopic examination shows that an organic origin cannot

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in any case be assigned to this rock. It must therefore have been produced by the precipitation from solution of carbonate of lime and carbonate of magnesia. This step gained, the question that now confronts us is as follows:—How was the *simultaneous* or practically simultaneous precipitation of those two salts brought about?

Very many explanations have been given of the origin of dolomite by chemical precipitation, but the great majority of these appear to me to have sprung into existence through the too fervid imaginations of their authors. The best known at the present day is perhaps that of Dr Sterry Hunt, the well-known Transatlantic chemist and geologist, who brings forward two reactions which, in his opinion, sufficiently account for the chemical formation of dolomite. Dr Hunt's reactions referred to appear to me to be quite possible in the laboratory under careful management, but there is certainly not the slightest evidence to prove that they occur at all in sea water. He says that if carbonate of soda ($Na_2 CO_3$) be mixed with sea water, the salts of lime and magnesia contained therein are decomposed, and carbonate of lime accompanied by a very small amount of carbonate of magnesia is at once precipitated. Quite so! but is there carbonate of soda to do all this in sea water?

Again, he says, "If water containing carbonate of lime be mixed with sulphate of magnesia as in sea water a double decomposition takes place, producing carbonate of magnesia and sulphate of lime, and that if more calcium carbonate be added to this solution further evaporation of the liquids may cause a precipitate of the two carbonates." Comment on this is needless.

Dr Sterry Hunt has also observed that at the *moment of its formation* in a solution, carbonate of magnesia is quite ready to unite with carbonate of lime. Does it? It may be quite ready to combine, but if it did in sea water we should have evidence of it in the quantitative composition of the deposit. We know, indeed, that combination between the two carbonates *takes* place (by some unknown method) under certain conditions in *fresh water*, with the result that curved crystals of bitter spar are produced, which give on analysis the essential and necessary proportions mentioned above; but such combination does not appear to occur in the water of seas or salt lakes.

Mr A. Irving[1] in his recent treatise on "Rock Metamorphism," has also tackled this problem (along with innumerable others), but has kept mainly on the lines of Sterry Hunt. He has some new ideas, however. He asserts that when calcium carbonate

[1] "Chemical and Physical Studies in the Metamorphism of Rocks" (a Thesis written for the Doctorate of Science in the University of London). By A. Irving, B.A., D.Sc., &c. Published in 1889 by Longmans & Co.

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and magnesia carbonate are brought together in sea water we get calcium chloride and magnesium carbonate. Do we? What a quantity of chloride of calcium we should find, then, in the sea water at the present time. But the bare fact is, the sea has scarcely ever the merest trace of this salt, and rivers have practically none of it at any time. Dr Irving rather sensibly objects to the view of Sterry Hunt, that dolomite was formed by the combination of carbonate of magnesia with carbonate of lime, at the moment of the formation of the former, but he descends or ascends into delightful absurdity when he goes on to say that "it is more probable that magnesium carbonate was in such cases formed simultaneously with calcium carbonate by direct action between alkaline carbonates and haloids of magnesium as well as calcium, for this simply assumes the presence of calcium chloride or magnesium chloride together in the same concentrated water." Far too much in my opinion is assumed here. What we sorely need is a small solid foundation of fact.

I have studied the subject of the formation of dolomitic limestones for some time very carefully, and have put my ideas strictly to the test of experiment, with, I think, very fair success. At any rate my theory of precipitation is an exceedingly simple one, and does not require the aid of elaborate chemical equations for its elucidation.

I suppose that by this time samples of the water of almost every known considerable river on earth have been subjected to analytical examination. Well, in every reliable report of such analyses that I have come across, I have observed that both carbonate of lime and carbonate of magnesia have been invariably detected in solution in these rivers, and that in about ninety-five cases out of a hundred those salts, together with calcium sulphate, constituted the most abundant soluble mineral ingredients of such waters. I am only speaking, of course, of reliable analytical reports, as some analysts are apparently quite unable from want of proper training to detect even the presence of magnesium let alone to determine the quantity of it existing in solution.

In the reports of two typical analyses of river water taken from Bischoff's "Chemical Geology," the first, that of the Thames at Kew, and the second, that of the Rhine near Basle, we see that 10,000 parts of the water of the former river contain normally about 15·57 parts of carbonate of lime, 1·67 of carbonate of magnesia, and 4·66 of sulphate of lime; and the same quantity of the water of the latter river 12·79 parts of carbonate of lime, 1·35 of carbonate of magnesia, and 1·54 of sulphate of lime. Springs are generally, as one would naturally expect, found to carry a considerably higher percentage of soluble mineral con-

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stituents than rivers, and, as a rule, the most constant and abundant of those ingredients in spring water are carbonate of lime and carbonate of magnesia.

We have then everywhere on the land-surface of the globe rivers (and springs, runlets, &c.) which are continually pouring enormous quantities of calcium carbonate and magnesium carbonate into the seas and lakes.

It has been already noticed by scientific observers that fresh water and salt water do not naturally mix well or at all rapidly together. When fresh water is introduced into a vessel containing salt water, say, an aquarium, it remains altogether on the surface, being of less specific gravity, unless the whole is properly stirred or mixed. The fresh water of rivers is not thoroughly mixed with the salt water of bays, but flows off as a more or less independent sheet on the surface, and only at a considerable distance from the shore is a proper mixture effected by the unceasing action of waves or currents. It is well known that in the South Atlantic the fresh water of the Amazon can be detected nearly or quite a hundred miles from the mouth of that river. The fresh water of the Volga is also noticeable for many miles into the Caspian Sea, and the same fact has been observed in the Dead Sea a long way in front of the embouchure of the Jordan.

It is evident, therefore, that the soluble salts of rivers are conveyed in their original medium for a considerable distance into the sea or salt water lake into which they ultimately pass. We have next to consider what happens when a proper mixture of the salt water and fresh water is effected.

From experiments which I and others have done, we learn that calcium carbonate is much less soluble in salt than in fresh water. Mr Anderson, the chemist at the Granton Station for Biological work, has very thoroughly investigated this subject of solubility, and published the results of his researches in the "Proceedings of the Royal Society of Edinburgh." He shows very clearly that all forms of the normal mineral carbonate of lime (*i.e.*, calcite, limestone, coral, &c.) are, as I have said, much more soluble in fresh than in salt water. The isomeric mineral form, arragonite, which appears to be an exception, need not be taken serious account of here, as its occurrence, compared with the other and normal variety, is so very limited. By recent experiments I have also proved, to my own satisfaction, that carbonate of magnesium is, as regards solubility in the two liquids, much the same as carbonate of calcium. *i.e.*, it is distinctly less soluble in salt than in fresh water. In fact, the degree of solubility of magnesium carbonate in sea water appears to be almost exactly

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the same as calcium carbonate, though the solubility of the two carbonates in fresh water differs somewhat considerably.

When the proper mixture of salt water and fresh water has been effected, therefore, precipitation of the two carbonates must take place. This, I think, I have also proved by experiment. I procured two large beakers, and placed in one a rather concentrated artificial sea water, *i.e.*, water containing all the principal salts found in sea water in solution, in the natural proportions. In the other beaker I placed a nearly-saturated solution of amorphous calcium carbonate in distilled water thoroughly permeated by carbonic acid gas (CO_2). I poured the contents of the latter beaker into the former, stirred them well up together, and left the whole to settle for a week. By the end of that period a thin layer of carbonate of calcium was seen to be deposited on the bottom of the vessel containing the mixed waters. I repeated the same experiment with a solution of magnesium carbonate and salt water with a similar result. I afterwards added a mixed fresh water solution of calcium carbonate and magnesium carbonate to sea water, and obtained in due course a mixed precipitate of both carbonates, or an artificial dolomite.

Now let us see how the results of these experiments are corroborated by natural facts. The Mediterranean, which receives such a large drainage, has in solution in its middle portions, and that near the surface, never more than about 0·01 per cent. of carbonate of lime; while of carbonate of magnesia no more, as a rule, than an infinitely minute trace can ever be detected or guessed at at any time in its central waters; but the rivers which terminate in this inland sea all convey into it, day by day, very considerable quantities of both of those dissolved compounds. The Rhone, at Lyons, has never less than 1·5 per cent. of calcium carbonate, and 0·5 of magnesium carbonate in solution; and the Danube, at Vienna, contains about the same amounts, while many of the other rivers which pass into it carry forward still higher percentages of those salts. To sum up in a sentence, we may safely say that the average fresh water which enters the Mediterranean has in equal volumes more than a hundred times the amount of dissolved carbonates of lime and magnesia which the mixed waters of the sea are found to contain.

This striking fact shows that in the Mediterranean there must be either a constant precipitation of the carbonates in question going on, or their perpetual and almost complete removal must be accomplished by starving organisms. The tendency of modern research is to prove clearly that marine creatures have really little or nothing to do with the abstraction of the dissolved carbonates of lime and magnesia. The known facts are

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quite against any theory accounting generally for their removal in this way, and therefore we need not seriously consider that aspect of the subject at all. There only remains for us, then, the one likely cause, the other alternative—precipitation. In conclusion, as they may be of some interest, I append the three following additional illustrative examples. The river Jordan, which flows into the Dead Sea, is now known to contain a considerable percentage of the two carbonates of lime and magnesia, while the waters of that sea have practically none in solution. In this case at least, there being no organisms that could possibly effect the abstraction of those salts, their absence can only be accounted for by precipitation.

The North Sea, in its central superficial portions, has never more than 0·5 parts in 10,000 of calcium carbonate, and 0·1 of carbonate of magnesia, and yet the Thames pours into it at least 2 *per cent.* of the former, and 0·2 *per cent.* of the latter. In the central parts of the Atlantic or Pacific Oceans the carbonates of lime and magnesia cannot usually be detected at all.

Briefly, then, my theory is that the rock dolomite owes its formation to the great difference in the degree of solubility of calcium carbonate and magnesium carbonate in fresh and salt water, and that it is built up of a *mixture* of these two carbonates, which have been precipitated together because of their almost equally difficult solubility in salt water.

In further support of my theory, I may draw attention to the fact that chemists have almost invariably detected magnesia (generally in small quantity) in all varieties of marine limestone.

An eminent analyst, to whom I was talking about the subject-matter of this paper the other day, informed me that he was certain that all natural fresh waters contain a slightly larger percentage of magnesian carbonate than has usually been recorded, owing to the faultiness of the quantitative methods adopted by or even available to the chemist.

In general, we find that massive dolomite or magnesian limestone contains from five to six or seven times more carbonate of lime than carbonate of magnesia, and these are about the relative proportions of the salts that have been detected in solution in river waters.

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XV.—*A Theory of the Devitrification of Igneous Rocks.* By Alexander Johnstone, F.G.S.

(Read 20th March 1890.)

That the devitrification of igneous rock is brought about by regular aggregations or arrangements of the molecules of the substance, is evident from the fact that a vitreous rock which has the same composition as a holocrystalline variety always exhibits a lower specific gravity than the latter. For instance, if we compare equal bulks of obsidian and granite, two rocks which have practically identical qualitative and quantitive chemical compositions, we find that the former is the lighter of the two, both, of course, as regards weight in air and weight in water. This solitary fact is all that is necessary to prove that in the glassy obsidian there is less matter, and consequently a smaller number of molecules present than in an equal volume of its holocrystalline relative. If this be so, then the difference in the number of those infinitesimally minute units in each case must be due to the manner in which they are respectively arranged.

From the study of crystal development we know that the arrangement of molecules in crystalline matter must occur on some rigidly regular principle, and that it is to this regularity of arrangement that the form, optical properties, cleavage, and other important physical characters of crystals are wholly due. The plasma or mother liquor out of which the crystals grow, must, on the other hand, have its constituent molecules scattered about in some purely higgledy-piggledy fashion, as it exhibits properties the very opposite of those of crystalline material, and is, moreover, bulk for bulk lighter in weight.

In order that the confusedly arranged units of the plasma may gather into regular groups, they must be free to move of their own accord, or forced into movement by external agents. Should this power of ready motion be permitted them for a sufficient time, then the entire plasma will lose its irregular character and become a holocrystalline substance; but, on the other hand, if the movements of the wandering molecules are quickly arrested from consolidation due to the loss of heat, pressure, or from other cause, then the plasma will largely retain its primitive amorphous character.

The original ground-mass of igneous rocks is liquid, the quickly consolidated plasma is glassy, the slowly consolidated plasma is holocrystalline, and that which has solidified or become fixed in intermediate time is crypto- or semi-crystalline

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(so-called); that is to say, it shows a very minute and imperfectly crystalline matrix, in which the first formed large and more or less perfectly crystallised minerals are embedded. As there is not a real homogeneous glass in nature, all the varieties with which we are acquainted containing embryonal crystals, it is evident that the force which draws the molecules together in crystalline development must act, in molten igneous rock at least, at the beginning with a very considerable degree of rapidity.

Having arrived at this point, I am afraid somewhat precipitately, I now venture to suggest a definition of devitrification more precise and illustrative, in my opinion, than any of those usually given. The process of igneous devitrification I would define as the passing of a rock from a condition in which its molecules are irregularly arranged, to a state in which those bodies are regularly grouped. The facts that I have briefly detailed above are now quite established in modern petrology.

What I am chiefly concerned about in this paper is an attempt to ascertain and explain the nature of the force or attraction which, as I understand it, draws the molecules together, and holds them bound in some sort of stable union; that is, the force which brings about the devitrification of a rock mass. There are said to be four great attractive forces in nature, viz., gravitation, cohesion, magnetism, and chemical affinity; but there is much reason for believing that all of these are merely different aspects or allotropic varieties (if I may use this term here) of one and the *same* great universal power.

Gravitation and cohesion, however, as we know them, bring bodies together, irrespective of sameness of composition or properties, and the action of the two forces named always results in the formation of a mixture, the properties of which are a blend of the properties of its constituents. With chemical affinity it is different; bodies of the *same* composition, or of *unlike* composition, are brought together by this force and made to coalesce or *flow into one another*, and from this intimate diffusive union a substance is produced that possesses a structure and properties quite different from that of either of its primary ingredients. What is usually known as magnetism with us is a force that brings bodies together by certain parts, those attracted portions being known as poles.

Now, as the result of some experiments, and from numerous observations on the formation of solids from heterogeneous solutions, it appears to me that the phase of chemical affinity must always be immediately preceded by that of magnetic polarity. I can now state in a sentence the gist of my hypothesis of the devitrification of igneous rocks. It is accom-

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plished by the regular arrangement of molecules in groups; the attractive force which draws them together being, in my opinion, that of polar magnetism, and the force which destroys the individuality of each unit, and creates a new structure and character for the whole group, that of chemical affinity. If this hypothesis is at all likely to be correct, that is, if it can consistently occupy the true status of a theory, we should expect to find some evidence for it in the crystallisations from artificial solutions, and also, more particularly of course for my purpose, in the different fixed stages of devitrified igneous rock.[1]

If we watch, by means of the microscope, the crystallisation of sulphur from solution in a blend of carbon disulphide and Canada balsam, we shall observe at first that the drop of liquid on the slide is quite clear and apparently homogeneous; and at this stage we must suppose that the molecules of sulphur are kept apart by the resistance of the solvent. By-and-bye, however, as evaporation proceeds, the separating power of the solvent decreases with its bulk, and the inherent magnetism of the molecules becomes the ascendant force.

The molecular bodies are therefore drawn together in groups, and each group acting like the compound magnet which I suppose it to be, attracts surrounding molecules or smaller clusters of these units according to its strength, and thus continues to grow by these additions until it becomes large enough to be distinctly visible through the $\frac{1}{4}$-inch objective. At this stage we still see an apparently homogeneous plasma, but it is now crowded in a porphyritic manner with those rounded, isotropic aggregations of molecules, which their first scientific observer, Vogelsang, has called globulites. The latter bodies are themselves here and there also observed to be clustered together in an irregular fashion, the irregular, small, and rather opaque heaps to which they give rise being known as cumulites.

Now, when we watch the further progress of the crystallisation of this element, we always find that the globulites, besides forming cumulites, come together end to end in the following

Fig. 1. Simple Margarites.

manner, thus clearly exhibiting polarity in the mode of attraction (fig. 1).

[1] See Author's Paper on "The Classification and Evolution of Igneous Rocks." "Trans. Edin. Geol. Soc.," vol. v.

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Those coherent rows of globulites have been called, by the authority previously cited, margarites. They increase or become compound by the attraction of fresh isotropic spheroids to the poles, and areas approximating to the poles, of each of the little fixed globulitic magnets, as shown in fig. 2.

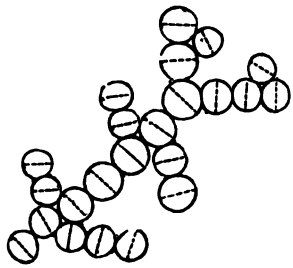

Fig. 2. Compound or Branched Margarite.

In the margarite condition each globulite, as I have here indicated, acts to a certain extent as an independent magnet, and attracts single globulites to it. But now, in the next stage of development immediately following, chemical affinity comes into play, and, as the result of its action, the continuity of each globulite disappears, and also its independent magnetic and other characters, and the whole colony *coalesces* to form a single club-shaped body or *longulite* (fig. 3), which behaves to external bodies, not as a series of magnets, but as *one* magnet.

Fig. 3. Longulite.

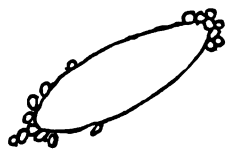

Fig. 4. Longulite attracting globulites.

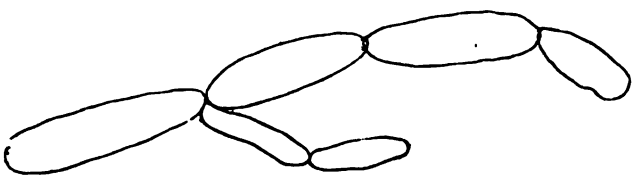

Fig. 5. A Longulite Colony.

It grows by the absorption of globulites which are first attracted to it by the magnetic force, and then incorporated into its substance by chemical affinity (fig. 4).

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Globulites and longulites have rounded outlines and are isotropic. Those two facts together show that in them the molecules, though drawn close to each other, are not yet arranged in any regular crystallographic manner. Longulites also frequently attract each other and form clusters (fig. 5), for which no name has been yet invented. By-and-bye the longulite developes angles at its extremities, and generally becomes faintly anisotropic, and on acquiring these crystalline attributes is at this stage known as a microlith. A longulitic colony developing in this way of course gives rise to a microlithic community, but as the result of the evolutionary change much of the original individuality of parts is here also, as a rule, lost by the coalescence of junctions brought about by the operation of chemical affinity.

The developments of the globulites, longulites, and microliths of a substance do not all proceed at the same rate. Some groups of molecules remain globulites, while others have passed through that stage into the longulitic and microlithic conditions.

If we observe the evolution of the sulphur crystals further we shall see that the microlithic rods attract each other by dissimilar ends, and arrange themselves side by side like a series of bar magnets (fig. 6), or gather together in a branched colonial fashion, forming, when chemical affinity has run the whole into one mass, a skeleton crystal (fig. 7), the interstices between the branches of which get gradually filled up with globulitic matter, &c.

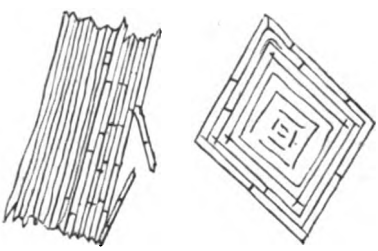

Fig. 6. Microliths building up crystals.

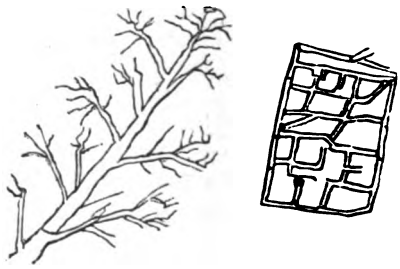

Fig. 7. Microliths forming skeleton crystals.

Ultimately, when the body of the skeleton crystal is filled up, it assumes the regular outward form of a crystal at or about the same time that its internal crystallographic characters are maturely developed.

In sulphur crystallising from a state of igneous fusion we can also notice the same stages of development, globulitic, longulitic,

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microlithic, skeleton crystal, and crystalline; only the microliths, or microlithic colonies, in this case, have a great tendency to rapidly rush together and build up sphero-skeletons or spherulitic structures around cumulites, &c.

We now come to look into the development of crystals in igneous rocks, and have no difficulty in finding varieties which have consolidated in each of the stages noticed above under the sulphur development.

First, we can easily find a piece of obsidian which when sectioned shows the structures indicated at foot of p. 108. Such examples of obsidian can be procured from the Isle of Ascension, and the Lipari Islands, &c. Many of the American obsidians show the margarite development excellently, and also the longulitic and early microlithic stage.

In the obsidians of Teneriffe and Cotopaxi the microlithic stage is very clearly exhibited, and in the pitchstones of Arran and Miessen the arrangement of microliths into spherules and other colonial forms, and skeleton crystals, can be very well observed; while the spaces between and around these bodies, and from which their constituents have been withdrawn, is often seen to be crowded with globulites. The fully-developed crystals in these glassy rocks also appear to have acted as magnets with prominent polarity, for their extremities are very commonly observed to be thickly studded over with microlithic rods, which evidently formed when the final stage of the solidification of the mass was drawing near, out of the innumerable globulites that were being drawn towards and into the substance of the crystal. That the mature crystals themselves very frequently, while floating about in the molten mass, attracted each other, forming paired and colonial forms, is, it seems to me, very evident from the numerous instances of simple and repeated *twinning* which we meet with in most rock-forming mineral species. I cannot account for the formation of twinning in any other way than by this induced sympathetic exercise of magnetic polarity. This view receives strong support from all that is known of the nature of twins. In these forms, as is well known, dissimilar ends or portions have always been brought together. Of course, after the preliminary magnetic attraction, chemical action must also, to a considerable extent, have come into play, but too late to effect a complete coalescence. From the obsidians and pitchstones we can pass without any break into the liparites or quartz-trachytes and trachytes, and through these into the felsites (which are apparently merely ancient forms of the trachytes), and thence into the granites, those higher changes in development taking place by the gradual grouping, first of the globulites, &c., into micro-

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liths to form the crypto-crystalline trachyte base, and afterwards of the microliths through the condition of skeleton shapes into more or less perfect crystals, to constitute the holo-crystalline texture of the granitic rock. We can also pass through the same stages of development from the tachylitic glass to the andesitic and basaltic rocks, and from these to holo-crystalline, Dolerite, Gabbro, and Picrite.

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XVI.—*Birkhill Fossils at Innerleithen, Peeblesshire.* By JAMES WILSON, Esq.

(Read 17th April 1890.)

THE importance of attending to fossil zones in mapping strata is now universally admitted. It may be said to be a necessity in all convoluted areas, especially when the deposition was slow. A recent illustration of the value of this method appears to me to be so striking that you will excuse my submission of it to the members of our Society.

The "Geological Magazines" for January and February 1889 contain a very valuable paper by Prof. C. Lapworth, on "The Ballantrae Rocks of South Scotland." Most of your members have no doubt read it, and I need not repeat its general bearings, except in so far as to give some point to the discovery of Birkhill fossils near Innerleithen. The paper describes the greater portion of the Southern Uplands as composed of two terranes, the lower one, the Moffat rocks, which Prof. Lapworth has very well worked out, and a superior terrane—the Gala or Queensberry series—of which much less is known in detail. The inter-relations of these terranes he, in effect, says are yet to be worked out before they can be accurately mapped, as they have been crushed up into innumerable wrinkles and puckers, the majority being overfolds or inverted folds in which neither dip nor strike are good guides to sequence.

But having given some years of study to these rocks, and having, he conceives, mastered some of the principles of rock elevation in hilly regions, he ventures on drawing three sections across the Southern Uplands—an eastern, a central, and a western section—and he hints that where the work of mapping has been carefully done, it will be found that his partly hypothetical sections will not be far from being correct.

It is well known that Prof. Lapworth was first to apply the general method of study to the Moffat series, and it is generally admitted that his conclusions regarding their sequence is wonderfully correct. Whether the sections he publishes along with the paper referred to turn out right on the whole remains to be seen.

The eastern section he carries through the Uplands extends from the Pentlands to the Cheviots. It shows a wrinkle of Birkhill shales coming to the surface at Walkerburn, Peeblesshire, a village one and a half mile down Tweed from Innerleithen. The only evidence on which he based this conclusion was my finding some fragments of *Rastrites maximus* in beds

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there, on which some curious terraces that have puzzled antiquarians can be seen from the public turnpike from Innerleithen down Tweedside. Lithologically, the Walkerburn strata presented not the slightest aspect that could ally them with the typical Birkhill shales of Dob's Linn. The latter are fine sandstones containing a considerable amount of carbonaceous matter. The Walkerburn beds are flaggy, highly arenaceous, and pale-grey in colour. But the Rastrites, though all fragmentary, were unmistakable, and it is the typical fossil of Prof. Lapworth's third or upper zone of the upper Birkhill division of the Moffat shales. Some of the other fossils of the zone were discovered along with the Rastrite, and it will appear to most geologists that it was a hazardous step to classify these rocks from one fossil. But a discovery last summer by Mr Robert Mathison, builder, Innerleithen, demonstrates the soundness of Prof. Lapworth's wide deduction from narrow evidence. One mile east from the Walkerburn beds, and, roughly speaking, along their strike—though no one could affirm there is no fold intervening—is a quarry on the roadside in Pirn Craig Hill which has long been worked. Mr Mathison's men in this quarry in June last came on what one might call a nest of shale between two beds of grit. On looking at the rock, Mr Mathison was so struck by its lithological resemblance to the Birkhill beds of Dob's Linn, that he concluded it represented that series. On splitting it up it was found abundantly fossiliferous, and a few of the least shattered specimens were forwarded to Prof. Lapworth who has named them thus: — *Monograptus cyphus* (Lapw.), *M. argutus* (Lapw.), *M. leptotheca* (Lapw.), *M. crenularis* (Lapw.), *M. tenuis* (Portlock), *M. gregarius* (Lapw.), *M. attenuatus* (Hopk.), *Climocograptus normalis* (Lapw.). Besides these there were *Dawsonia campanulata* (Nich.), *Discinocaris Browniana*, and probably an *Ontroceras*. In a letter to Mr Mathison, Prof. Lapworth writes:—"The find shows distinctly that you have met with my gregarius zone of the Birkhill shales. The forms of Discinocaris are very good, and remind me of Moffat and the north of England. To have found these fossils at Innerleithen is a capital discovery."

Prof. Lapworth divides the Moffat shales into three divisions, the highest the Birkhill shales, next in order the Hartfells, and lowest of all the Glenkilns. The Birkhills he has broken up into an upper and lower division, each consisting of three zones. The gregarius zone is the third from the bottom, and the top of the lower division. The *Rastrites maximus* zone is the highest of the three forming the upper division. In the full series in the typical area two zones intervene between the beds at Walkerburn and those now found in the Pirn Craig Quarry,

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and they may perhaps be come upon in this district. There are also two zones below the *Gregarius* band of which the typical fossils are *Diplograptus Vesiculosus* and *D. acuminatus*. These too, will, no doubt, be searched for by Mr Mathison.

I may add that the mass of the rocks in the quarry are hard grits dipping at a high angle, and the beds are marked on their surfaces with slicken sides as if the elevation of the beds had been accompanied with violent friction. The shale in which the fossils occur cannot be traced laterally in either direction, and is a mere patch between two beds of grit.

The quarry is on the southerly side of the hill, and its western side, which is washed by the Leithen, contains many fossil beds which have never been systematically exposed. Most of the graptolites I have seen taken from them are monoprionidian, and some of the beds are the well-known Grieston Series—certainly higher than the Birkhill Shales.

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XVII.—*Notes on some Irregular Forms of Stratification.* (*Abstract.*) By J. G. GOODCHILD, H.M. Geological Survey, F.G.S., *Lecturer on Geology and Palæontology at the Heriot-Watt College.*

(Read 17th April 1890.)

SEVERAL different types of irregular stratification were reviewed, and the origin of each was discussed. Some of the less-perfectly understood forms of disturbances of later date than the strata affected were noticed first. Among these some reference was made to the crumpled and disturbed bedding resulting from "crust-creep;" and some mylonites and allied rocks were exhibited in illustration thereof. Another class of disturbed strata, very similar in general appearance to the last, was typified by the crumpled and contorted Skidda Slate from the granite aureoles of the Caldbeck Fells. Here the arenaceous members of the Skidda Slate series are transformed into good typical mica-schist, the foliation coinciding with the bedding, and still remaining but very little disturbed. The associated argillaceous members of the same series have undergone a different set of changes through spotted schist, knotenschiefer, and andalusite schist, in no case attaining to mica-schist, as do the arenaceous beds. Near the granite margins the andalusite schist appears to have been at one time softened, and, while in a plastic condition, to have undergone considerable disturbance. The original bedding is still traceable in many cases by means of the less-altered arenaceous laminæ. The argillaceous laminæ of the rock have been driven forward, crumpled, and piled up over these, in a manner very similar to the crumpled layers of the mylonites. But, in the present case, no traces of *shearing* can be detected. The displacement of the layers has evidently taken place while the rock was in a plastic condition, and when the disturbance ceased, the whole mass was welded anew and compacted into rock harder than before. This case was adduced as an exceptional illustration of the fact that there is really a certain amount of mechanical disturbance accompanying the intrusion of large masses of plutonic rock, although the amount of disturbance is by no means commensurate with the bulk of the rock intruded. In the vast majority of cases, as is now well known, plutonic rocks seem to have eaten their way into the rocks they invade, and *re*place rather than *dis*place the strata whose original position they occupy. The results of contact metamorphism may thus, on a limited scale,

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closely imitate those of metamorphism under plutonic conditions, as where crust-creep, on a large scale, affects rocks under conditions of pressure, temperature, and moisture, sufficient to bring about a general rearrangement of the rock constituents.

As another illustration of the disturbance effected by igneous rocks, the author referred to the crumpling and reversed faulting of both the tuffs and the sedimentary rocks in the neighbourhood of heavy masses of lava, and he pointed out that the half-consolidated strata beneath and around such floods of molten rock can hardly fail to escape being rolled out, and otherwise disturbed by the invading mass. The writer is disposed to refer some of the very curious contemporaneous contortions in Carboniferous rocks—such, for example, as seen in Craigleith quarry, near Edinburgh, to disturbances arising from the cause just mentioned.

Some of the contemporaneous contortions seen amongst tuffs, especially those of the Lake District, the writer attributes to the deposition of fine tuffs or of volcanic muds on a sloping surface, and their subsequent slipping under the accumulating weight of material afterwards piled up behind.

A few other, less remarkable, cases were noticed, and the effects upon submerged strata of floating ice and other bodies in motion were briefly discussed. The "trail," so characteristic of the Thames valley deposits, and of other strata accumulated in the presence of floating ice, was referred to, and illustrated by drawings.

Some of the contortions in the later pleistocene strata around Edinburgh, the writer thought, might be due to the same causes, *i.e.*, the impact of floating masses of ice at a time when the estuary of the Forth was dammed up by the ice in the North Sea.

Most of the contortions in the glacial deposits proper the writer is more than ever disposed to refer to the irregular downsettling of the ice-sheet upon the half-consolidated sediments (the drifts) that were being liberated from the body of the ice-sheet as it melted *in situ*.

Some minor contortions were ascribed to the withdrawal of support through the removal of rock matter from beneath. The "pipes" in chalk districts afford good illustration of this. Further illustrations are supplied by the dissolution of gypsum, of rock salt, or of any other easily-soluble rock material.

The decomposition of included masses of vegetable matter, originally of great bulk, is another source of disturbance.

Yet another cause of disturbed bedding is the growth *in situ* of beds of gypsum, which has frequently ensued as the result of segre-

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gation at a lower level from percolating solutions. The increase of bulk consequent upon the transformation of Anhydrite into Gypsum may, really, in a few cases, contribute to the same result.

In conclusion, the author noticed the effects of blistering and small local contortions, due to the evolution of marsh and other gases from muddy sediments, and to the uprising of springs in areas where the saturation plane of the rocks tend to rise above the surface.

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FIFTY-SEVENTH ANNIVERSARY MEETING.

27th November 1890.

XVIII.—*Obituary Notice of* DAVID MILNE-HOME, Esq. of Wedderburn and Milnegraden, LL.D., *President of the Society.* By RALPH RICHARDSON, F.R.S.E., *Vice-President.*

IT was with poignant regret that the members of our Society learnt that, on 19th September last, our much-beloved and respected President, Mr Milne-Home, was dead. Although his last and protracted illness had, for a lengthened period, deprived us of his presence, we could not forget the former days of his health and vigour, when he constantly presided over our meetings, and when he brought to bear upon our discussions all the strength of a mind ripened by more than half-a-century devoted to his favourite science, Geology. Nor can we forget the dignity, the urbanity, or the geniality with which he presided at our meetings, elevating us all by his presence, and conducting the business of the evening in a manner showing that he had been long accustomed to fill similar positions. Indeed, wherever Mr Milne-Home went, he was sure to be called upon to occupy a prominent position. He was Convener of Berwickshire, of which he was one of the greatest landed proprietors. He was Vice-President of the Royal Society of Edinburgh, and also of the Royal Scottish Geographical Society. He was Chairman and Vice-President of the Meteorological Society of Scotland, and devoted much time to its work. We elected him one of our Vice-Presidents in 1871, and he held the office till 1874, when he was elected our President, in succession to Dr Archibald Geikie, now Director General of the Geological Survey.

Mr Milne-Home was born in 1805, being the son of Admiral Sir David Milne, a distinguished naval officer. He was called to the Scottish bar in 1826, and when he died was the second oldest advocate. He assumed the name of Home on his marriage, in 1832, with Miss Home, heiress of the estates of Billie and Paxton, in Berwickshire. In the year 1844 Mr Milne-Home was senior Advocate Depute, his juniors being Charles, afterwards Lord Neaves, David, afterwards Lord Mure, and John, afterwards Lord President Inglis. Mr Milne-Home preferred the life of a country gentleman to that of a judge, and relinquished the law for his landed estates. He was devoted, however, to science, and so distinguished himself (as I shall presently narrate), that the University of Edinburgh conferred upon him, in 1870, the degree of Doctor of Laws. Mr Milne-Home's brother Admiral of the Fleet Sir Alexander Milne Bart.

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was in command successively of the North American and West Indian, and the Mediterranean stations, and by visiting him at his official residences in Jamaica and Malta, our late President acquired much valuable scientific information, of which he afterwards made good use.

To follow so enthusiastic a worker, so fluent and graceful a speaker, and so ready a writer as Mr Milne-Home into all the fields through which his active intelligence and indomitable energy successfully carried him, would involve a lengthened memoir, dealing with many scientific and other associations. In this Society we are interested mainly in his geological career, and I shall therefore confine my remarks to his geological work and writings.

Mr Milne-Home was elected a Fellow of the Royal Society of Edinburgh so long ago as 1828, when he was twenty-three years of age. His early devotion to geology is proved by a circumstance which his daughter (Miss Milne-Home) has brought under my notice, that, in a letter dated 1820, written when he was a boy of fifteen, her father gives a description of a tour which he had made in the Trossachs, and mentions his finding some specimens of mica slate, with garnets imbedded in them, in a cave of Rob Roy's near Loch Lomond. That from an early age he excelled in geological science is evidenced by the remarkably able papers he read before the Royal Society of Edinburgh soon after he became a member.

1. *Midlothian and East Lothian Coalfields.*

In the preface to the first edition of his "Geology of Fife and the Lothians," Charles Maclaren, afterwards the President of our Society, writing under date October 1838, says: "Mr David Milne, advocate, read, in the Royal Society last winter, two able papers on the Midlothian Coalfield and the superficial deposits of the basin of the Forth."

The papers in question were read in February, March, and May 1838, and form the well-known "Memoir on the Midlothian and East Lothian Coalfields," which first established Mr Milne-Home's reputation as a geologist. It was printed in the fourteenth volume of the "Transactions of the Royal Society of Edinburgh" (p. 253), extends to 105 quarto pages, and is illustrated by numerous maps and sections. A more valuable contribution to economic geology was rarely made, and the surveyors of H.M. Geological Survey, as well as Mr Charles Maclaren, duly appreciated it. The former refer to it in their "Memoir of the Geology of the neighbourhood of Edinburgh," published in 1861, and point out (p. 103) that Mr Milne-Home proved Maclaren to be in error as to the age of certain rocks.

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Mr Milne-Home's indefatigable industry was early shown, for in this fourteenth volume of Transactions are other two lengthy papers from his pen, the first a "Notice respecting the depletion or drying up of the rivers Teviot, Nith, and Clyde, on the 27th November 1838" (p. 449), and the second, a "Notice of two Storms which swept over the British Islands during the last week of November 1838" (p. 467). These Memoirs evince his early devotion to the exact observation of natural phenomena, as well as the untiring energy with which he threw himself into any subject he took in hand.

2. *Geology of Roxburghshire.*

The fourteenth volume of Transactions was published in 1840. Four years later the fifteenth volume appeared, and again Mr Milne-Home's pen was prominent. His "Geological Account of Roxburghshire" (p. 433), which is accompanied by a geological map of the county, extends to 69 quarto pages, and describes, in a masterly manner, the leading geological features of Roxburghshire. He has also a lengthy contribution "On a remarkable Oscillation of the Sea, observed at various places on the Coasts of Great Britain, in the first week of July 1843."

3. *Parallel Roads of Glen Roy.*

In the sixteenth volume, published in 1849, we find a paper which introduces our late President to us in a character which he was quite ready to assume if absolutely compelled to do so, namely, as a determined but always most honourable and gentlemanly combatant. The paper to which I shall now refer is a memorable and famous one, as our President's antagonist on this occasion was none other than the illustrious Charles Darwin, who, with the candour which distinguished his great mind, admitted himself worsted in the encounter.

Darwin had visited the Parallel Roads of Glen Roy in 1838, and says he spent "eight good days" over them.[1] His mind being full of the elevation of the South American coast, he concluded that the roads were due to the same cause. His paper on the subject was published in 1839, in the "Philosophical Transactions of the Royal Society of London." It was for this paper that Mr Milne-Home went in the Royal Society of Edinburgh, and, in papers read during March and April 1847, smote Darwin hip and thigh. Darwin groaned under the castigation, but admitted that he richly deserved it. "Mr Milne having attacked my theory," he wrote to Sir J. Hooker, "made me

[1] The references to Darwin are taken from the first volume of his Life, published in 1887.

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horribly sick." As to his paper, Darwin confessed, "This paper was a great failure, and I am ashamed of it. Having been deeply impressed with what I had seen of the elevation of the land in South America, I attributed the parallel lines to the action of the sea; but I had to give up this view when Agassiz propounded his glacier-lake theory. Because no other explanation was possible under our then state of knowledge, I argued in favour of sea-action; and my error has been a good lesson to me never to trust in science to the principle of exclusion."

Mr Milne-Home's memoir in the sixteenth volume is entitled "On the Parallel Roads of Lochaber, with remarks on the change of relative Levels of Sea and Land in Scotland, and on the Detrital Deposits in that country." Whilst Mr Milne-Home destroyed Darwin's marine theory, he did not, like Darwin, accept the glacial one of Agassiz. He belonged to that resolute band of geologists of which the Duke of Argyll, Sir William Dawson, and himself were the most distinguished members, who always regarded Agassiz's theory with suspicion. He had no objection to floating ice and local glaciers, but as to a vast moving ice-sheet or ice-cap, he never would accept such a theory.

Consequently, his theory of the formation of the Parallel Roads of Lochaber was not that of Agassiz. I shall best state it from his last revised edition of it, contained in a paper which he read before the Royal Society of Edinburgh in May 1876, and of which he sent me a copy as it appeared in the Society's Transactions (vol. xxvii. p. 595. 1876).

The theory which, after long and minute observation, he adopted to account for the formation of the puzzling Parallel Roads is stated by himself shortly as follows:—

1. The valleys in which these roads occur have been occupied by lakes which subsided from one level to another, as the blockages of the lakes were worn down.
2. These blockages consisted of detritus (clay, sand, and gravel), which had been spread over the country when it was submerged, and which filled all the valleys, up to considerable heights.
3. The blockages were from time to time worn down, and the materials composing them removed by the action of rivers, the cutting power of which would increase as the sea sank from its original high level to its present level."

Mr Milne-Home's Memoir on this interesting subject is well illustrated by numerous woodcuts and charts, and although his conclusions are diametrically opposed to those of others who

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have attempted to explain the phenomena, the care and elaborateness with which he discusses the problem are evident on every page.

With regard to the more general question of the physiography of Scotland before the Lochaber lakes were formed, Mr Milne-Home, in the same Memoir, joins issue with the school of Agassiz, by stating the following propositions :—

1. That before these Lochaber lakes were formed, the whole country had been under the sea, and that during this submergence, currents with floating ice spread gravel, sand, and clay over what was then the sea-bottom, filling hollows on what is now the land, and causing rocks to be smoothed and scratched by the passage and pressure upon them of stones and pebbles.
2. That the sea prevailed to a height of at least 3000 feet above the present sea-level.
3. That the direction in which this current flowed over this part of Scotland was from the W.N.W. (magnetic), judging by the transport of the gravel and boulders, and also by the markings on the hills and rocks ; but that this direction was modified by the hill ranges and submarine valleys over or through which the current passed.

I should mention, ere passing from this subject, that Sir Charles Lyell, in his "Antiquity of Man" (4th edition, p. 306), points out that Mr Milne-Home was the first to ascertain that the "col" at the head of Glen Glaster coincides exactly in level with the second or middle shelf of Glen Roy—a most important discovery, for it compels theorists to explain how the water which formed the uppermost shelf or road in Glen Roy was prevented from escaping over the "col" at the head of Glen Glaster.

4. *Origin of Boulder Clay.*

In the twenty-fifth volume of the Society's Transactions, published in 1869 (p. 655), we find a Memoir on quite as puzzling a subject as the Parallel Roads—the origin of Boulder Clay. Mr Milne-Home, in this Memoir of 36 quarto pages, discusses the "Boulder Clay of Europe," and concludes (1) that glaciers were not the agents to which boulder clay owes its origin ; (2) that the sea shells contained in the deposit indicate its submarine origin ; (3) that pressure by some agent of enormous weight and magnitude is also indicated ; and (4) that icebergs and shore-ice would probably answer these conditions, and are seen now in the Arctic regions producing similar effects.

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5. *Post-Roman Elevation of Land.*

In his next contribution to the Transactions we find Mr Milne-Home again as a fighting man. His antagonist on this occasion was that eminent geologist, Dr Archibald Geikie, who, in a paper read before the Geological Society of London in 1862, and published in its Journal (vol. xxviii., p. 218), had stated that the Roman wall between the Forth and Clyde "was built when the land was at least twenty feet lower than at present." Dr Geikie had satisfied Sir Charles Lyell of the correctness of his theory. Mr Milne-Home was not so easily convinced. He visited the spot on the shore of the Forth at Bridgeness, where our late Vice-President, Mr Cadell of Grange, had discovered a Roman tablet, and in a Memoir, published in vol. xxvii. (p. 39) of the "Transactions of the Royal Society of Edinburgh," in 1876, under the title "On the Supposed Upheaval of Scotland in its Central Parts since the Time of the Roman Occupation," he stoutly controverts Dr Geikie's theory. With regard to the Roman tablet, Mr Milne-Home remarks: "If the land was twenty-five feet lower than now, then the tablet and the wall in which it was fixed must have been six feet under the sea at every tide, and must also have been so exposed to the beating of the waves that neither tablet nor wall could have stood many weeks." Our Secretary (Mr H. M. Cadell) discussed Mr Milne-Home's Memoir in 1880, in a paper published in the fourth volume of our Transactions (p. 25), and whilst stating that the evidence seemed to show that "the sea has not retreated to any great extent since the beginning of our era," points out several imperfections in Mr Milne-Home's argument. However, there is no doubt that on the main question Mr Milne-Home triumphed, and Sir Charles Lyell gave emphatic testimony to this by withdrawing his adhesion to Dr Geikie's theory, and declaring in the fourth edition of his "Antiquity of Man" (preface, p. vi.), that the theory "that there had been a rise of twenty-five feet in post-Roman times is no longer tenable."

6. *High Water Marks on Tweed.*

Mr Milne-Home was a master of physiography, and no detail in a landscape escaped his eye. His Memoir in the twenty-seventh volume (p. 513) of the "Transactions of the Royal Society of Edinburgh" is a proof of this. It was published in 1876, and extends to 49 quarto pages, and in it he describes "High water-marks on the banks of the river Tweed, and some of its tributaries, and also of drift deposits in the valley of the Tweed." Mr Milne-Home argues that "if the existence of old sea margins up to

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even the smallest heights above the present level of the sea be admitted, then all the rivers must necessarily have had their channels *that much higher* than now: in which case, flood marks must have been made on their banks at heights suited to the higher channels so occupied by them.

7. *Reports of Boulder Committee.*

The Royal Society of Edinburgh having, in 1871, come to the conclusion that the boulders, kaims, &c., of Scotland were well worthy of study, appointed a Committee, with Mr Milne-Home as Convener, to investigate and report upon them. A Committee with such a Convener did, I need hardly say, an immense amount of work. Its Reports, ten in number, are published in the seventh, eighth, ninth, tenth, and eleventh volumes of the Society's Proceedings, and will ever remain a monument of our late President's extraordinary zeal and industry. The Reports extend to 400 pages, and contain ample lists of boulders, &c., and abundant information regarding them, the whole constituting one of the most practical, and therefore one of the most valuable, bits of geological work ever done in Scotland.

8. *Estuary of the Forth.*

As I have shown, Mr Milne-Home's contributions to geology are chiefly to be found in the "Transactions of the Royal Society of Edinburgh," where he early made his mark, and of which he died a Vice-President. He wrote two geological books, however, the first of which was published in 1871, under the title of "The Estuary of the Forth and adjoining districts viewed geologically." This book was published in time for the meeting of the British Association in Edinburgh in 1871, and contains a mass of information and of facts noted by the author for many years in his note-books.

9. *Ancient Water-Lines.*

The other book by Mr Milne-Home was published in 1882, and bears the following ponderous title, "Traces in Scotland of Ancient Water-Lines, marine, lacustrine, and fluviatile, with some account of the drift materials on which these traces are imprinted, and speculations regarding the period in the world's history to which they may be referred, and the climatic changes they suggest." This valuable work also shows the immense pains taken by Mr Milne-Home to verify geological facts, and the enthusiasm with which he pursued his investigations. His daughter (Miss Milne-Home) remarks in a letter to me: "Certainly, as long as we can remember, his geological expeditions were among his greatest enjoyments, and they were

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continued as long, indeed longer, than bodily health permitted. In later years his indomitable spirit and eager zeal carried him on, when advancing years made the effort almost too much. Sometimes, when he caught sight of some distant boulder on a Highland hillside, after a day's walk already too long for him, he would make his servant bathe his head with sal-volatile, and set out again till he came close to the object of his interest."

10. *Addresses to our Society.*

As Vice-President and President of our Society, Mr Milne-Home favoured us with many contributions, which will be found in the second, third, fourth, and fifth volumes of our Transactions, and which deal generally with the Post Pliocene Geology of Scotland, of which he was admittedly a master.

Gentlemen, I have now set before you our late President's geological career. It was that of a patient, conscientious, enthusiastic observer of nature, whom no toil could thwart, no difficulties deter. It is a labour of love to me who knew him so well, and respected him so much, to lay this slight wreath upon his tomb.

And now, in conclusion, as to my personal reminiscences of Mr Milne-Home, I reflect with pleasure upon the fact that it was he who, at his own suggestion, proposed me for election as a Fellow of the Royal Society of Edinburgh in 1875. He also added my name to his Boulder Committee, and I read one of its Reports to the Society, in his absence, by his special request.

Of course, when I acted as Secretary of this Society, I saw a great deal of Mr Milne-Home. He was always a good friend to our Society. As he mentioned in his address to us in 1872, he recommended our Society for a Government grant, when examined by the Duke of Devonshire before the Royal Commission appointed to report on the assistance which should be given towards the prosecution of science. He was himself a liberal contributor to our Society's funds.

I have already alluded to his enthusiasm for boulders, to which the Reports of the Boulder Committee bear such ample testimony. I remember one day in 1874, when I was busily engaged in my office as a Writer to the Signet, Mr Milne-Home unexpectedly called upon me and announced that he had learnt that a remarkable striated boulder had been found in a sandpit at Tynecastle, near Edinburgh. He said his carriage was at the door, and he proposed that we should instantly visit the sandpit. I pleaded business engagements, but his mind was made up (he was a very determined man), and no excuse would be taken. So we drove off together, discovered, examined, and

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measured the boulder, much to his satisfaction, with the results contained in his paper in the second volume of our Transactions.

I had my revenge, however, afterwards; for if he carried me off on that occasion, I carried him off on another, and more important one. As Honorary Secretary of the Scottish Geographical Society, I was anxious to find a fitting speaker to greet Mr H. M. Stanley, when he addressed the Society on his return from Africa in 1884, being the first public meeting the Society ever held. I at once thought of Mr Milne-Home, one of the Society's Vice-Presidents, so called at his house in York Place. To my disappointment he announced that nothing would induce him to move the vote of thanks I desired, as he had ceased speaking in public. He invited me, however, to remain to luncheon, and there I met his son, Colonel Milne-Home, who proved for me a gallant and willing ally. We both pressed upon Mr Milne-Home the duty of appearing, and although he did not promise to come, he attended the crowded meeting in the Music Hall, and delivered one of the most graceful and telling speeches I ever heard. His tall, handsome figure, his earnest manner, his polished diction, and his well-chosen words, are known to all of you; and on the particular occasion to which I refer, he made as favourable a public appearance as I am sure he ever made in his life.

But now he is gone! and science in Scotland is the poorer by his removal. He was a splendid, and unfortunately a rare, specimen of a Scottish country gentleman devoting himself to, and excelling in, intellectual pursuits. If Scotland had more landed proprietors like Mr Milne-Home, it would be well for their order, it would be well for our country. It is men like him who elevate the class to which they belong in the nation's eyes. He was one of the true aristocrats—not merely a possessor of position, wealth, and lands, but of knowledge, public spirit, ability, and intellect.

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY,

SESSION 1890-91.

ANNIVERSARY ADDRESS.

XIX.—*Landscape Geology: A Plea for the Study of Geology by Landscape-Painters.* By Mr HUGH MILLER, F.R.S.E., F.G.S., H.M. Geological Survey, *Vice-President.*

(18th December 1890.)

SINCE the occasion of Professor Alleyne Nicholson's address to this Society, early last winter, one of the most interesting of the public events that have taken place in Edinburgh has undoubtedly been the meeting of the Art Congress. I believe I am right in saying that Art has hitherto been the most reticent of the professions. As a class, artists are fully engrossed by studies which engage the hand and the eye, but not the tongue or the pen—studies which demand nothing less than entire and lifelong devotion. Except for their amiable habit of dining together from time to time, and of occasionally making presidential and other speeches, we should have heard almost nothing about them—from themselves. Until Mr Frith published his amusing "Reminiscences," I believe there was scarcely such a thing as the autobiography of an artist, if you except the strange memoirs of Benvenuto Cellini, and that quaint and charming autobiography of Bewick, and, in our own day, the autobiography of Holman Hunt. It was therefore of unusual interest, if only as a revelation of personality, to hear or read papers from the hands of such men as Watts and Briton Riviere. But this is by no means all, even from the popular point of view. The proceedings of the Congress presented us with teaching of a most pleasing kind—that kind in which the teachers are competent

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men who simply talk together and discuss and debate, while the taught have nothing to do but to listen. A wise old essayist, in an essay "On Regimen of Health," recommends all such as would study what he quaintly terms *the principles of long lasting—i.e.*, of health and long life—to be sure to entertain "variety of delights, wonder, and admiration, and studies that fill the mind with splendid objects." Many of us sooner or later begin to discover—generally, I think towards middle age—that there is nothing that fills the mind with a variety of delights so measureless, so truly recreative, as the study and love of the beautiful, whether it be in Nature or in daily life.

> "Its loveliness increases; it . . . still will keep
> A bower quiet for us, and a sleep
> Full of sweet dreams and health and quiet breathing."

There is perhaps a time coming when, as a matter of mere "regimen" and ordinary education, there may be more cultivation, not only of the *pleasures* of taste, but of what I may call the artistic *understanding*,—the art of conceiving of things artistically, or in their artistic completeness. And it may come all the sooner because of this annual Art Congress.

For my own part, I read the pages of the *Scotsman*, during the days of the Congress in Edinburgh, with unusual interest. There was one subject, however, of which I saw no mention whatever—a subject which a body of artists meeting in this country of uplands and highlands, in a city owing so much of its beauty to the rocks and heights among which it is set, might perhaps have been expected not altogether to forget. I refer to the relation which may be held to subsist between the study of landscape-painting and the study of the rocks,—using that word in its wide geological sense, as including everything from granite to gravel,—that form the basis of landscape. I observe that at the recent meeting in Birmingham, again, there were papers read on almost all the relations of art to modern life—art in relation to industry, art in relation to technical education, art as applied to jewellery, advertisement as a field for design, &c.; but of geology still not one word, and of science of any kind only the merest mention. This subject, which I have described as Landscape Geology, is one that has of late years been much, and, I believe, unjustly neglected; and I have ventured to select it as the subject of the annual address to this Society.

But, it may be asked, What business have I, a mere working geologist, to take up a subject that demands so much culture, so much refinement of taste, so much special study, such wide knowledge? I have to confess at once that I am not, in any sense, an expert in art. I cannot pretend to be anything more than one of

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these average persons who take delight in a good picture and a fine scene. But the subject has very seldom been treated of,—hardly at all since Mr Ruskin wrote the first and fourth volumes of "Modern Painters," now from thirty to forty years ago,—and perhaps never by one who is by profession a geologist. If only on this account, there may be found an artist or two who may care to spend a vacant hour in listening to a geologist, who in pursuit of his profession spends a great part of his life among the scenes and inmost haunts of Nature, and who counts it as one of the grand acquirements of his life that he has learned to look upon Nature, however humbly, with something of the artist's eye. Of one thing, at least, I am sure: in referring to painters I desire to speak with the greatest respect and deference—I might well speak of many of them with something like affection—as of men whose works have been to me for years an abounding source of the purest pleasure.

But it may be objected that science and the fine arts cannot be, and ought not to be, brought together. "Science and poetry," it has been said, "are to a nicety diametrically opposed;"[1] and poetry is, of course, the atmosphere and breath of the fine arts.

Certain it is that science and the art of the landscape-painter deal with different aspects of Nature, and assume different attitudes of mind. There will little work be done while the geologist is opening his heart to the beauties of the landscape; nor will the picture gain in "feeling" while the artist is engaged in analysing the peaks of the mountains into cones of denudation, or the rocks of the waterfall into rhombs and lozenges, defined by planes of stratification and jointing.

But I venture to demur to the statement that science and the fine arts, or science and poetry, are at opposite poles. There is a whole region in which, like the halves of the sphere, they inevitably come into contact. Science, however distasteful it may be to the young and æsthetic, is only the careful investigation of the truth of Nature; and of the truth and the poetry of Nature the exquisite art of the landscape-painter is an *expression*. Science deals, as it were, with the body, the structure, the habits, and finds it impossible, happily, to forget the mind that informs them; art deals, as it were, with the face and the expression of the face. But do I assert too much if I say that in the study of landscape art, as in that of the human physiognomy, to understand the expression of the face you must know something of the body? Certain it is that without some knowledge of the body, its parts and habits, and what an old writer might term its *humours*, and needs, and cravings, as well as of the mind that informs it, and without a constant (though perhaps unconscious)

[1] Dr John Brown, "Horæ Subsecivæ," pp. 229-231. See Appendix I.

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reference to these,—the human face would be an enigma, and physiognomy, whether as an instinct or a science, could have no existence. Is it pressing analogy too far to say that it is not altogether otherwise with the art of the landscape-painter, who is the student and interpreter of the face and expression of Nature? Can he show us the face of Nature without any knowledge of her structure, and the expression of Nature without any knowledge of her ways? He is to delineate for us the stream, the cloud, the bird, the tree, the rock: can he delineate them in ignorance that *this* is flowing water, and *that* floating vapour? can he delineate them so well caring nothing for the habit of growth or *kind* of the tree; nor for the meaning of the lines that seam the iron front of the rock?

Such is not the teaching of art in any other of its departments. The historical painter cannot know too much of history, even of its springs and hidden sources: it is not enough for him diligently to study costumes. The painter of *life* cannot know too many of the phases and deepest emotions of life. The portrait-painter will paint incomparably better portraits if he have a knowledge of men and their physiognomy that will confer on him the gift of reading the lines of the human countenance,—the signs of the habits and struggles, and noble or mean ambitions, that mould the character. It is only the landscape-painter who is advised to remain in healthful ignorance of all the deeper workings of the Nature which he studies, lest, forsooth, he should make geological structure-diagrams of his pictures, or mayhap come incontinently to despise the storm and the lightning as exhibitions merely of the electric spark or of a measurable wind-motion. I venture to say that, if he be not able to think and reason for himself upon the subjects with which he deals, he will by just so much be less the interpreter and more the copyist, and without extraordinary powers of faithful observation will miss half the suggestions and half the refinements of the landscape. "A mere copier of Nature can never produce anything great."[1]

The truth is that the landscape-painter, like his brother artists, cannot know too much, *if he know it aright.* But it is also true that the artist, above all men—the poet alone excepted—has need to assimilate his knowledge perfectly. What in the preacher is but a touch of pedantry, and what in the good lawyer may only serve as an amusement to the bench, in the artist is dangerous, if not destructive, to pure artistic feeling. And thus instinctively the artist learns to wear his knowledge "lightly, like a flower"—or, rather, he learns to *wear* it not at all; for since his art is undoubtedly a magic synthesis of the

[1] Reynolds, "Fourth Discourse."

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objective and the subjective—of Nature with himself,—his knowledge, that it may not in any way intervene between Nature and himself, becomes, as it were, a part of his *own* nature. And therefore it is true that science should be presented to him, not in its incomplete stages as inquiry and induction, but, so far as possible, as full and perfect knowledge. The laws of perspective will become to him mere matter of common-sense; his knowledge of anatomy and geology and botany will bear the same relation to his mind that anatomy itself does to the human body,—being something entirely out of sight, the very fact of it forgotten—*clothed upon* with the beautiful. I cannot believe that science will rob the Academies of any eminent Associates or great works. Nature is greater than our knowledge of Nature, by whatever name we call it: and looking into her unfathomable eyes—all the more intense in their meaning, all the more alluring, and all the more fathomless to him whose knowledge is great—the true artist will no longer be conscious of his little knowledge, or the pride of his acquirements, but, abased in the hopelessness of showing her to us as she is revealed to him, will see only her transcendent and incommunicable beauty. "I could name half-a-dozen painters who have been ruined by science," says one who must have known hundreds of artists in his time, "but they were all men of feeble artistic gifts to begin with."[1]

Far be it from any one to apply pure truth or rigid science to the study of landscape. They who cry out for truth, nothing but truth, scarcely realise to what it would bring them. The human eye is not a surveyor's instrument. "Every hill," it has been said, with much truth in the seeming exaggeration, "is half the height it looks; every curve looks twice as round as it is; every interesting feature is insignificant." Exaggeration unconsciously mingles with every feeling of admiration, wonder, or awe. The human mind, I repeat, is not a mere clinometer or measurer of angles; nor are the hills, even to the geologist, masses solely consisting of beds of rock laid at ascertainable angles, with divisions and breaks called joints and faults, and having certain cognisable outward shapes, the result of denudation. Geology is not what we look for in landscape. We look for the soul of the truth, not the whole body, still less the skeleton.

Last summer I was sailing up the coast of Norway, between the islands and the mainland, towards Bergen. On the outer side were miles of naked rocks, rising, so far as I can recollect, to perhaps six or eight hundred feet above the sea. Their glaciation, marked by their curved and ice-worn outlines, was as distinct as in a diagram. They were traversed by upright

[1] P. G. Hamerton, "Thoughts about Art," p. 367.

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planes of jointing laid as closely—so it seemed in the distance—as they could have been drawn by a fine pen. The whole rock had the appearance of having been cut straight downwards into thin slices, and then carefully put together again in such a manner that you could still see the joinings traced in dark lines—for it was a dull day—as if by the ink of the etching-pen. The planes of stratification or foliation were perfectly defined, marking the rock into slabs laid sloping towards the mainland, and shelving to the sea like artificial embankments of stone, up which the waves were sliding. It was a remarkable geological diagram.

It was singular, but it was the mere skeleton of landscape. Its lines were those of a ground plan or elevation; their intersections were like those of a scaffolding. There can have been few on board the steamer who did not turn with pleasure to the other side of the ship. *There*, on the mainland, the atmosphere was such that the structure seemed to be defined by comparatively few lines, but they were master lines. Hills rose behind hills, and towered into mountains; there were snow-gleams from misty heights, amid a whole world of chiaroscuro; and in the foreground lay the naked rocks and the changeful sea. The one was an excellent geological model upon the natural scale, the other was mere "mountain truth" expressed in the highest spirit of art. Yet I venture to think that the one would greatly help in the interpretation of the other; and for a very obvious reason—the one was constructed, so to speak, *upon the lines* of the other. The one was anatomy, the other was the living presence; the one was the skeleton, the other was body and soul.[1]

[1] I am not unmindful that there must be many things which appear differently to the eye of the artist and the eye of the geologist. The eye sees what it brings with it the power of seeing, and, it may be added, the proclivity to see. Passing through some of our Highland valleys, for instance, the geologist may be tempted to regard the morainic mounds, with which they are sometimes for miles bestrewn, with a certain impatience, as little better than mere geological *litter*. They are, in truth, in one sense, only a sort of rubbish-heaps left behind by the glaciers of the Ice Age. They are often the most irregular mounds, thrown into groups as waggon-loads may be shot into heaps, with but little beauty in their short curves and little colour in their spare *cleading* of sombre heather; the arid subsoil breaking through the thin peat, and the peat mingling with it like grime.

But if you will accept her leading, Nature will not allow you lightly to esteem anything of hers as litter. You have been following the stream downwards. The hummocks, the moraine mounds, which the inevitable eye of the poet so long ago saw to be

"Hillocks dropped in Nature's careless haste,"

before there was a science capable of investigating them, have become dappled with birchen shaws and covered with the feathery juniper, with its sprays of waxen green; the loose stones, half buried in bushes, are hieroglyphed over with moss. See these green knolls of exquisite sylvan loveliness, where the ferns wave by day and the fairies dance by night! See these deep hollow coverts underneath the flaky foliage, where the mavis sings to his mate! Nature, once again, will not allow you to dismiss any of her works with con-

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There is only one other aspect of the general relation of science to landscape-painting which I need refer to here. I find that Mr Hamerton, the well-known editor of the "Portfolio," distinctly admits that science has its own proper place in the training of the artist. The efficiency of the artist, he says, depends in a great measure on his vivid recollection of form and effect; and, by assisting the memory to retain these with a precision not otherwise attainable, science is of the same sort of use to him that the map is to the traveller, when it informs him where the places lie, when it guards him against mistakes, and assists his topographical memory.[1] And, again, it is to the artist what the rules of grammar are to the writer.[2] This is true, so far as it goes, and true especially of the sciences which Mr Hamerton names—*i.e.*, perspective, optics, and anatomy. But there is a much deeper truth beyond it. Science may become much more to the artist than mere chart or mere grammar; it may be to him what knowledge is to the understanding, reasoning, mind—something that may exercise, vivify, and fertilise his mind every conscious moment, lending to the eye a deeper insight and a more "precious seeing." It may seem to stand aside in the supreme moments of creative activity, but it is even then scarcely more separable from him than his own powers of reason. Nor is exact truth at war with poetry—and here I return to the point from which I started. "Poetry," says Wordsworth, "is the breath and finer spirit of *all* knowledge; it is the impassioned expression in the face of all science." If he be not endowed with any large measure of that "finer spirit," the artist who sits close to Nature's feet, and who knows her ways, will at least be a correct topographer, or a faithful naturalist; his love of Nature may even shed over him a something hard to distinguish from genius itself. But if he possess that spirit, that greatest of endowments, he will, like Tennyson and Browning, the great scientific poets of the age, stand upon the supreme attainable altitude of the vantage-ground of truth, from which alone he can command all the visible horizon, ascending, as if at will, to the purest heights, or revelling amid the gloom and the cross-lights of the most shadowy recesses.[3]

tempt as mere rubbish-heaps. You have climbed to the crown of some higher knoll, and you cast your eye back at the moraines of the upper valley. And lo! they too have been transformed. A haze has fallen over them, and a cloud rests above the haze, and a shaft of sunlight falls through the cloud. Their own outlines are as black as jet. Where there seemed to you before to be only meanness, there is now mystery; and what seemed scarcely worth a glance from the geologist, is now a subject for the reverent study of the artist. Nature, if you will allow her, will always assert herself as the Supreme of Art.

[1] P. G. Hamerton, "Thoughts about Art," p. 357.

[2] "Portfolio Papers."

[3] See Appendix III., "Science and the Poets."

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Perhaps the best commentary on the relation of science to landscape-painting is to be found in the works of artists themselves,—in those studies the *science* of which—I now refer exclusively to geology—is so simple, that ordinary faithful observation and good common-sense can take its place. I turn, for instance, to Mr H. W. B. Davis's picture in this year's Academy, "The Picardy Dunes." It is an excellent example of faithful delineation of the "topographical" kind. Every hollow, almost every dimple, among these low sand-hills tells of wind and blinding drift—as the snow-wreaths do after a winter's storm, or like the waves of the open ocean when the wind has gone down, and the sea heaves under a quiet sky. It is now calm. The lie of the *bent* will tell you from what direction the wind came; you can almost fancy you detect those broken stalks that whirl round and round in the breeze, describing circles on the sand. The rabbit-burrows will tell you that the wind has not been violent; they will be buried out of sight in the next gale, like the track which the sheep are leaving. Yet the picture is not suggestive only of aridity and of blinding blasts of dry sand. The sheep can find pasture, and have milk for their lambs. There are trees which suggest the neighbourhood and the hand of man; they will remind you of the *Pinus maritima*, which has checked the march of the sand over many a league of southern France, causing the sandbanks to be clothed with evergreen woods, and the surface of the sand itself with softest mosses. Many of these things may have been in the mind of the artist; to me his picture is eloquent of them. He has certainly studied very carefully the geology, in its widest sense (*i.e.*, I believe, its *artistic* sense), of the sand-dunes.

I turn to another picture, and this, as it happens, is also by Mr Davis,[1]—his pleasing study, "A Placid Morning on the Wye." It leads us away to a spot where a few stones lie across the stream, almost like a natural *weir*, or a place which you would choose to lay with stepping-stones. The quiet river, bearing almost unbroken the reflections of cattle that are stepping into it, glides down a short slope, perhaps some hidden outcrop of rock,—bending into a sudden rush and darkening, with a gleam among the dark, as it turns; and then it breaks; there is a white fringe of foam stretched across from side to side,—a dance of foaming water,—a spurt thrown up here and there into the air; and then the stream quiets down into ripples flecked with foam, and glides on as before; and the sudden

[1] I regret that I have described two pictures from the same hand. I chose them not altogether from their merits—considerable as these are—but as illustrations.

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outgush of sound, as you may fancy, shows you how calm is the day.

Now, I must confess that an appreciable part of the charm of this picture, to me, comes from a detail apparently very trifling —the ease with which the water glides among and over the loose stones of its bed. They are smooth,—you see it by their wet gleam; and the water scarcely breaks upon them: their planed sides *are sloped gently towards the current.* Exactly upon the same principle the marine engineer lays his stone embankment and builds his sloping jetty, at an easy angle towards the waves; in order that, in washing up the incline, they may encounter the smallest possible modicum of resistance—wasting their force in mere sliding. And here, by a kind of natural selection under the influence of the water, the stones of the stream do exactly the same thing for themselves. They are under the same law under which the mist, clinging to the hill, drifts in sloping wreaths before the mountain breeze, or the bird floats sideways on the wind,—watch it how it dips its wing to let the current glide over it—how it is flung away to leeward when the wind catches it from below,—the same that determines the shape of waves of water, and ripple-marks in sand, and the moulding of the curves of ice-worn rocks. Details such as these are not mere *et cetera.* They are the illustrations of great laws and principles. The river will not glide with all the grace of Nature if the simple stones in its bed do not slope to meet its flow.

For the sake of those, however, whose inclination it is to undervalue pictures such as the two I have partially described, as mere careful delineation, mere "topographical" painting, I take an example from one of the most idealistic productions of Turner, —his extracrdinary creation, "*Quivi Trovammo,* the Dragon of the Garden of Hesperides." I refer here only to Mr Ruskin's plate in "Modern Painters,"[1] which, as he explains, is a sketch on the steel adapted for the purposes of his work. I have not seen Turner's original for many years.

The dragon is almost in the act of raising himself on to a rock, and lies partly in a hollow of its side. His claws clutch it frightfully; the hind limb stretches far forward to grip the edge of the stone, with a hideous suggestion of tension and irresistible strength. His small crocodilian head is the very spirit of evil.

You see at once that the rock consists of a hard and ancient gneiss, ribbed and gnarled at the surface. The ribs of the rock have the same direction, and as much as possible the same character, as the wrinkled and stony rings—the broadest of them scarce broader than an iron quoit, that encircle the

[1] Vol. v. p. 303.

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monster's body. A cunning carver might have hewn them both from the same stone. The rock and the dragon are *as if of one kind and one age.* The rock is of that primary kind which all through the century has been taken as the product and almost the type of mysterious fiery processes carried on in the very depths of the earth; and the dragon is—"that *old* dragon." It is a strange touch of genius.[1]

But there are in geology the materials for a thousand touches of symbolism as effective as this. The day may come when they will be more often applied and more fully understood: it will then be no longer necessary to argue that science and poetry are not "to a nicety diametrically opposed."[2]

I need not seek to multiply instances. It will some day be conceded, I repeat, that there is a whole world of knowledge to furnish them without limit. But there is, I regret to say, a reverse side from which my subject compels me to draw one or two illustrations. Some excellent artists there are, close to touch with Nature in many respects, who seem to have and to prefer a geology of their own, the works and ways of which, and I will even add, the *poetry* of which, are not at all those of Nature. There is one well-known painter of Highland scenery, an R.S.A. of well-earned distinction, who, as I have observed, has an affection for painting boulders; sometimes they form his foregrounds, sometimes they dot his hillsides. Now, if we were to seek for poetry in rocks, it might perhaps *most* readily be found in those strange masses of stone—strewn broadcast over the hills, or scattered from the hills over the plains—that have been let fall, so often among strange surroundings, from the grasp of the ice which, it is now part of common knowledge, once covered the face of this country. Even their scientific names—boulders, erratics, perched blocks—suggest something strange. You see them standing on the verge of precipices; you meet them lying like huge roc's eggs in solitary hollows; you find them like some kind of memorial-stones, preserved, for

[1] In the original I find that the gnarled appearance of the rock disappears. Turner seems to have liked to paint gneiss—he appreciated its ribbed strength and its sinuous lines; but this looks more like granite. The idea of unity between the rock and the monster, however, is quite as strong in the picture as in the plate. The side of the topheavy crag on to which he has crawled, and where, with intense watchfulness, he remains, might almost do for part of the body of another and greater dragon.

[2] It is curious to note how shallow have been the arguments on the affirmative side of this question. The views into time and space, glimpses of which have been afforded us by astronomy and geology, have been on every hand characterised as wonderful. It is equally generally admitted that these sciences are fitted to take an important place in the training of the imagination—and a very important place, I believe, it will one day be recognised as being. And *yet*, they are diametrically opposed to poetry. As if *wonder* and *imagination* could be far from *poetry!*

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curiosity's sake, among corn-fields and pastures. To the country people of Scotland they have always been instinct with wonder and rude poetry. They have been flung, as many a legend tells, by giant hands from distant crags; or they have been transported by the black art; or they have been dropped where they lie by the Evil One himself. There is scarcely a noticeable "erratic" or group of erratics in the whole south of Scotland that has not its own expressive name—Samson's Putting Stane, the Auld Wives' Lift, the Witches' Stepping Stanes, the Warlocks' Burdens.

But in the canvas of this eminent artist, so far as I have seen, the strangeness and the poetry seem to vanish. His boulders, to put as fine a point upon it as possible, have the beauteous semblance of a flock at rest—being indeed, in plain words, as like one another as sheep, or peas and beans, or marbles, if you imagine these objects to be roughish, greyish, of different sizes, and covered with an invariable glaze. Now, regarded from our present point of view, this want of individuality and expression marks a distinct degeneration of feeling. It was with other sentiments that our fathers and our ballad-poets regarded these foundlings of Nature. Nor is the blame, I fear, in any way to be laid to the door of science. The boulders of this artist's canvas are no more geological than they are poetical: they have not even the aspect, like a sandstone boulder lying out on a limestone rock, of a thing out of place.

For one other illustration of this less agreeable part of my subject, I turn to a group of blocks (not boulders) that occupy the greater part of a study of Hagar in the Wilderness, recently exhibited by a well-known R.A. The blocks occupy, I said, the greater part of the picture, and they become, therefore, what rocks or stones seldom are in landscape, almost *more* than accessories. They are intended to furnish the great secondary idea of the study—utter desolation, stony despair. Yet there they are, without mass or weight, hardness or boldness, or even so much as proper confusion; they are not even like real stone. The forsaken woman is represented as shrinking, with clasped hands down-wrung, close in to the side of the one huge block, as if to escape from the cry of her boy. It would be an effective idea, if only the great stone were well drawn; but unluckily there is a kind of lintel-shaped slab interposed which remarkably resembles some rude garden seat or some "rest and be thankful" by the wayside; on this she is seated—very uncomfortably; the great block itself has an unfortunate resemblance to the artificial rock of a photographer's studio.[1]

[1] This is, or used to be, a block of wood covered with French leather, the puckerings of which represented the joints of the stone.

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Other blocks, apparently intended as thrown in confusion, on the left, have a certain resemblance, I observe, to the panels on a door. As an inevitable consequence of all this ineffectiveness, the central figure, which ought to appear as if lost amid the deepest desolation of the desert, is more like that of an actress surrounded by the furniture of the stage.

Now, I am quite sure that any painter of this artist's eminence could have done much better than this, if he had thought it worth while to study the positions, or what I must call the *attitudes* of the fallen masses on any rugged hillside. It is singular how few of them look like mere inert masses; they look what they are—blocks arrested in the very act and attitude of falling: some of them sliding down the slope longways, in the line of least resistance—perhaps with their heavier end first; others as if actually overbalancing and toppling over; others with an appearance of holding back, almost as if rearing—these are the masses against which others have afterwards fallen, so that they seem, by a trick of the associative faculty, as if pushing back in the press; and here and there some cyclopean mass may be seen held up by a multitude of others, as if by a hundred hands. Their position, on a slope of 25 or 30 degrees, with the bank clear away below them, heightens the apparent imminence of their situation. The ground has often slipped from their lower sides—many of them thus appear to overhang; or again, it may be heaped against them from above. and they may then seem to bear what is known in some parts of the country as "the weight of the hill." All these appearances affect the mind of the curious observer. A fleet of fishing-smacks in a gale, scudding close-reefed before the wind, or careening till their masts are level with the fronts of the billows, is not more full of varied expression than the fallen blocks on a hillside. Even when they are viewed from the extreme distance, clinging to the hillside, "like the small dust of the balance," they appear as if caught in the very act of dropping, and all but actually in motion still.

It is no part of my desire to suggest to the artist how to make usè of details like these; he can make use of them in numberless ways of which I can have no conception. But permit me to give one more illustration. I take it this time, not from art, but from legend.

There is a strange mediæval legend called the "Amen of the Stones,"—the story of an aged apostle, wandering from place to place, quite blind, and led by a little boy, but preaching as he went the Word of God and the Gospel of the new Name. The story has been told in English verse, so simply and concisely,

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by a sweet poet of the south of England, that I employ her words as much better and more direct than my own :—

> "And it befell, that to a lonely vale
> O'erhung and compassed with huge blocks of stone
> The child did guide his footsteps; and thus spake
> (Less with an evil purpose than the light
> And idle thoughtlessness of boyish jest):
> 'Here, father, here are men that wait
> To hear thy preaching!'
> Then the old man roused
> The strength that was within him, . . .
> Exhorted, warned, rebuked and comforted.
> And when, as ever was his wont, he closed
> The holy lesson with our Lord's own prayer,
> And said, 'Thine is the Kingdom and the Power
> And Glory ever more'—then rang a sound
> As a thousand voices thro' the vale,
> 'Amen, Eternal God! Amen, Amen!'
> Then the boy trembled, and he cast him down
> Before the old man's feet, and told his sin.
> And the blind priest made answer to him thus:
> 'Hast thou not heard, my son, should men be mute
> The very stones would cry aloud? . . .
> Play with God's Word no more, for it is quick
> And powerful, sharper than a two-edged sword,
> And if men to its voice make stone their hearts,
> Will for itself make human hearts from stone.'" [1]

I have at times given myself pleasure in imagining the scene of the striking story thus simply told. I have imagined the *valley* of the stones :—A great vale, with its slopes rising into lofty walls of rock dimly pillared, and lost far above in a vault of clouds. A flood of light comes down the valley from the evening sun, touching with its radiance some of the intricacies of the cloudy roof. There are deep shadows in far-off recesses of the sides, and indistinct shafts of light and tracts of haze, like the light in a cathedral, cast

> "Down sidelong aisles and into niches old."

At the nearer end there is a pile of rock standing rather by itself—not much different from many that you may see in any valley, but such as in this scene you cannot mistake. For in front of it, as if before an altar, is the blind apostle, his sightless eyes raised towards the light, and full of the divine fervour of his mission; and beside him is the child, pale with affright. It is the moment of the Response. All around and far up the slopes is the vast concourse of stones, like the waves of the sea in the evening, when every hollow is a deep shadow and every wave raises itself like a living thing. The multitude is instinct

[1] Poems, by Emmeline Hinxman (2nd edition), p. 119.

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with an appearance of motion arrested in suspense. It is like an assemblage that has risen to its feet and that is straining as if to get nearer—leaning over as if to fall, crowding as if drawn irresistibly towards the centre; and every here and there is one that stands as if pushing back in the throng to save himself from being thrown forward.

There are certainly the materials of a great picture in this story; and the artist who will paint it as it deserves will do much to silence those "undeserved scorns," according to Mr Ruskin, "that are flung upon the most familiar of our servants —*stones*."[1]

Thus far I have endeavoured to enforce and illustrate two positions, and I have deemed it necessary to treat them in detail.

1*st*. That Science and Art or Science and Poetry are not diametrically opposed, but that there is a wide region in which they come into living and inseparable contact; and

2*d*. That in the special science of geology—even in the patient study of the loose stones and tumbled *débris* of the surface—there is much that the landscape-painter will find to add enormously to his grasp of the truth of Nature, and to the force of his illustrations and symbolism.

In what follows, I go on to speak of rocks and masses (mountains) of rock, saying a few words

1*st*. On mountain form.

2*d*. On expression in rocks—including that of their texture, of their structure, and of their individuality;

and then on the subject

3*d*. Of teachers and studies.

First, then, with regard to *Mountain Form* as now understood by artists in landscape.

Of the general idea of mountain form and "mountain truth," as shown in the outlines of all good artists of recent date, I am glad to express, as a geologist, my unqualified admiration. Mountains are no longer depicted, as they were by some of the earlier landscapists, as mere heaps and burdens of rock and stone laid upon the surface of the earth. They are generally recognised as having a connection—graceful, or noble or majestic —with the earth itself. They may be clad with soil and alluvium, with screes, or peat and drift, as the bones are clothed with flesh; or covered with vegetation as the body is clad with robes; but they are on every hand recognised as the protuberances and unbarings of a structural framework below. And in general, also, they are depicted with perfect truth of feeling—not as rent and torn by disrupting forces from within, but as wasted and sculptured by the forces of "denudation" at work without.

[1] "Modern Painters," vol. v. chap. xviii.

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It might, perhaps, be shown that this development of the idea of mountain truth in the hands of our noble school of naturalist painters and that of the Nature-poetry of the century in the hands of Wordsworth and the Lake School and their forerunners, side by side with geological science (and let it be remembered that Britain has produced a school of physical geology from which the rest of the world has been content to learn), is not a thing of accident, but that they have all been part, so to speak, of one great Renaissance of Nature. But this is a subject for another hand than mine.[1] What concerns me just now is to ask whether, in spite of all the attainments that may be so justly praised, there is not a danger ahead. Already to my eye there begins to be a noticeable repetition and lack of freshness and variety of idea in the canvas of modern painters of the Scottish school. I do not say that it ever amounts to conventionality; but since repetition of idea and loss or absence of touch with Nature tend to *result* in conventionality, I ask whether the danger, if it be a real one, will not be most effectively surmounted by increasing the *breadth* of idea with which the artist approaches this part of his subject.

The elements that make up the structure of all our mountains in this country are simple enough; planes of stratification; planes of jointing; faults, which are joints attended by displacement; cones of denudation; ravines branching up among the cones; crags and precipices; screes, which are always paler than the rock from which they fall; drift, and moraines, and peat, &c. I would fain have the artist able, in virtue of his training, to recognise all these, and to combine them to whatever extent he may deem necessary into such a general idea of mountain architecture as is borne upon the eye to whatever may be his point of view.[2] More than this,

[1] It would be interesting to follow out this parallel. Certain it is, that whilst the Continent has produced no Wordsworth and no Turner, it has also produced no geologist comparable to Lyell. It is true, also, that just as there were Nature-poets before Wordsworth, so there were Nature-artists (and mountain truth in art), before Turner—a fact which Mr Ruskin, I fear, has forgotten. Let anyone sit down for ten minutes before Cozen's picture of an Alpine mountain range in the present exhibition of "Old Masters" in Burlington House, and in these noble peaks—in their loftiness and in their dimness, and the light on the faces of their crags, and the mist lifting off their snow, he will have before him a study that, in its perfection of form and truth of suggestion (I do not refer to the foreground, nor to the colour, which is almost a monochrome), that might illustrate "Modern Painters" itself. It is dated 1791—about the time Turner first left London.

[2] It is possible that I have laid myself open to misunderstanding here. Let me guard against being supposed to ask that the artist should *read his ideas of structure* into the mountains by quoting an anecdote of Turner. "Turner, in his early life, was sometimes good-natured, and would show people what he was drawing about. He was one day making a drawing of Plymouth harbour, with some ships at the distance of a mile or two seen against the light. Having shown this drawing to a naval officer, the naval

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I would have him open his mind to the ideas of strange vicissitude and awful age in connection with rocks and mountains. It has sometimes struck me as curious how much reverence we have for the antiquity of a ruin, how very little for the vast age of the mountains. Why should we approach the ruin with veneration, and approach the crag with no feelings except those of the moment—pleasure, perhaps, or a pleasing fear of its beetling front and great fallen stones; never any sense of its majesty of antiquity. We do not ordinarily associate the idea of age with *natural* features; the span of human life, or even that of the existence of the race of men, is too immeasurably little compared with the age of the "everlasting hills." Rocks, moreover, are common; fine ruins are few. Ruins are pregnant with human associations; rocks have none. But you remember that old man whom Endymion found sitting "upon a weeded rock" under a cliff by the sea. You remember his robes "o'erwrought with symbols"—

> "Every ocean form
> Was woven in with black distinctness: storm
> And calm, and whispering, and hideous roar
> Were emblemed in the woof: with every shape
> That skims or dives or sleeps. . . .
> And there was pictured the regality
> Of Neptune."

It is no fable or poetic dream. Such are, in very truth, the warp and woof of the mountains; and, like these, are the symbols of their past history. I do not say that these are truths which will often engage the artist's mind, or that can be expected often to employ his hand, any more than they engage the mind and hand of the poet; but they certainly open to him a whole range of new feeling; and I have *this* confidence in him—that whatever he strongly feels he has the power to make us feel.[1]

I cannot help thinking that, as a rule, artists look upon rocks as in themselves rather expressionless objects,—little worth the trouble of study,—scarcely better than, so to speak, the lay figures of the landscape, and as such, in almost their only place, and put almost to their only use, when clothed with the drapery of woods and fields, of furze and heather, endued with jewel-

officer observed with surprise, and objected with very justifiable indignation, that the ships of the line had no port-holes. 'No,' said Turner, 'certainly not. If you will walk up to Mount Edgecumbe and look at the ships against the sunset, you will find you can't see the port-holes.' 'Well, but,' said the naval officer, still indignant, 'you know the port-holes are there.' 'Yes,' said Turner, 'I know that well enough; but my business is to draw what I see, and not what I know is there.'"—The "Eagle's Nest," Lecture VII., p. 123.

[1] It would be foreign to the scope of this paper to do more than merely refer to the rocks viewed as a *cabinet of designs*. But in this department the artist or designer will find the fossil shelves of our geological museums full of the most varied and instructive suggestion.—See "Testimony of the Rocks," p. 217.

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gleam of water, and the magic of atmosphere and cloud. It is too seldom that we see a study of rock *per se* in our galleries. We have Alma Tadema's delineations of polished marble, exquisitely cool and true—with reflections that have all the softness of translucency; we have the massive strength of hewn stone in the St Paul's or the St Martin's-in-the-Fields of Mr Logsdail's canvas, with the black stains throwing forward the grey; but seldom, indeed, have we an adequate treatment of the strength, and mass, and majesty of *rock*, or of the contortions of the strata that still seem to writhe in the solid, or even the gentle outcrop that breaks the soft slope of the hillside.

Rocky foregrounds in especial, if I am not mistaken, are rarer in art than in Nature, and simpler. A complex of rock most artists seem to avoid. In what there is presented to us I have seen much honest imitation, and some true insight and genius; but there is also much timidity, much mere copy work, not a little sameness. I am sometimes reminded, indeed, of the Cockney who took a house in the neighbourhood of London, surrounded by trees, and who, when a friend asked him of what sort were the trees, innocently replied, "Oh, well, just the *ordinary* tree, you know." I sometimes think that there is a formation, imperfectly known to the geologist, that deserves to be known as the ordinary rock.

This brings me to speak of rock-texture. May I say that it is one of the first and most essential, and even emblematic qualities of rock or stone, that it should look *hard?* I do not know how to put the statement so mildly as I would like; but rock ought not to resemble wood, or cork, or leather and prunella; it ought not, in general at least, to look as if it would melt in the sun or the rain: it should not, if possible, even look as if it were varnished. And, above all, it should not look too like a substance which, by a strange fatality, painted rocks are very apt to resemble—that most inartistic material—putty. No doubt there must be considerable difficulty in painting rocks, with their essential qualities of hardness and general roughness and dulness of texture, in such a material as oil paint. It is almost fatal to their naturalness to be glossy or oily. In thinking over this subject, I observed a note which I had written in one of my recent catalogues. It was placed against the name of a study, not of rocks at all, but of the open shore of the sea, a study entitled "The ribbed sea-sand." The picture was a laborious study of ripple-marks in sand, not quite my own taste in art, but carefully painted. How came it that, in spite of all its care, the ripple-marks seemed as if formed not of sand at all—for sand ought to look as if its grains would move freely at a touch, whether of the fingers or the foot, or the gentle

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lifting of the currents of water that make ripple-marks—but as if done in some substance sticky and sluggish,—resembling mud! The answer seems to be this: that the artist had not quite overcome the difficulties of the material in which he worked. His ripple marks, being done in oils, looked oily. The same may be said of many specimens of painting in *rocks*.

But this, I regret to say, is not all. In too many instances it is possible to criticise the *form* quite as unfavourably as the texture. I note too many rocks that are shapeless and leaden; too many that are full of lines, but that have their lines really in confusion; too many that, although carefully painted, are like rock-specimens laid out on a table; too many that are scarcely painted at all.[1] I believe there is one cardinal objection to much more than half the painted rocks that have been seen in the Royal Scottish Academy of recent years: they add almost nothing to the force of the pictures, except as mere blank masses to relieve the distances. A fact so general cannot be without some good reason. And I fear that there can be but one—want of sympathy with this part of the subject. I venture to believe that this want of sympathy is only the result of want of study—of firm knowledge and easy grasp.[2]

It is hardly worth while to turn aside to argue that rocks are *not* expressionless objects. How is it that they smile upon us in the sunlight, and frown upon us from below the castle? How is it, when you come upon one of these little red crosses cut in the stone of the wayside among the Pyrenees or in Norway—marking some spot where in these lonely places some one has met with death—that they seem, on the moment, to close more grimly round? Why do they look down with haggard faces from the side of Glencoe?

One of the most impressive ruins I have ever seen is a round corner tower of Heidelberg Castle—*die gespraengte Thurm*,—blown up by the French in 1689. One whole side or great segment of the tower has been lifted bodily into the air, and the huge mass now stands detached, with its base thrown outwards and its top hurled over towards the centre, as when it fell tottering after the moment of the explosion. There it stands—what was once its upright wall sloping at an angle of some forty-five degrees, and the courses of its immense masonry laid aslant, like sloping strata of rock. It is perhaps the most impressive monument of the power and horror of war to be seen

[1] "Nothing more distinguishes good mountain-drawing (and I will add good rock-drawing) from careless and inefficient mountain-drawing than the observance of the marvellous parallelisms which exist among the beds."—"Modern Painters," iv. p. 218.

[2] As a Scotsman I am sorry to observe some of the best rock painting I have yet seen, exhibited in London, and under English-sounding names.

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in Western Europe; and it is none the less so because it is now half-mantled with vegetation, in one of the loveliest of scenes, and beside a lovers' walk.

I believe I have some general idea how a dramatic artist would treat a subject like that. I will not inflict upon you any more description; but I am quite sure that he would not be satisfied with producing a contrast in red stone and green leaves. Only let me say but this. The expression of disrupted mass in that broken tower of Heidelberg Castle is a mere incident, if you compare it with the racked and writhing forms of rock to be seen in some of those regions where the crust of the earth has suffered the stress and convulsion of its earlier ages—a stress so enormous, a convulsion so terrible, that they might well seem to have produced, in solid mass of stone, the agonies of an Inferno itself. A history such as theirs is not altogether sealed up in expressionless silence.

Rocks, then, are by no means without expression; but there may be much difficulty in adequately representing it. There are subtleties of form and line as delicate as those that inform the human handwriting,—subtleties of grouping and shading which the genius of a Turner might discern, or which by painful study may be copied, but to which some intelligent knowledge of the subject is surely the best key.

This leads me on to a subject, however, which I must touch upon lightly—that of *individuality* in rocks and mountains. Rocks, it is unnecessary to say, are of many different characters and formations, such as granite; basalt; gneiss wrinkled and ribbed; splintering slates and quartzites falling into slopes—like those of the sides of cones—stratified sandstones; sometimes in shelving ledges such as Bewick loved to draw in many a sweet scene on the Tyne, sometimes in level courses, like those that bar the sides of the mountain pyramids of Assynt; conglomerates; limestones; boulder clay, and many others, all of them very different from one another. "Is it too much to ask," says a well-known geologist, "that the artist shall not give us *slate* where there is only *gneiss*, or granite boulders where there are none?"

Notwithstanding what I have already said, it is a question I do not seek to press. Let but the *expression* be adequately studied, and every artist will answer questions such as this in his own way. Specific differences and distinctions may then look after themselves; and instead of specific individuality we shall have something much better—*artistic* individuality. I for one have no desire to go geologising through the picture galleries.

But there is one kind of individuality which it certainly

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seems desirable, if possible, to maintain. Some time ago I was looking at a painting by a well-known artist whose pictures are always well hung in the Scottish Academy—of a scene on the north side of the Dornoch Firth, at a place called Spinningdale. It showed the opening of a stream among some rocks upon the low shore of the firth. I had been on the spot a few weeks before; I remembered having admired that dark rock festooned with drooping branches, with the water of the stream turning and dimpling at its foot; I had stood for some minutes upon that little platform of rock within the curve of the stream; I had looked seawards over those stones, with their coating of vivid green weeds, among which it entered the water, and over the firth, veined with currents and dappled with light breezes, to the low hills of the opposite coast. But the hills—what had he done to them! Their familiar curves were changed into a row of knots, to the best of my recollection like the knots of a blackthorn cudgel, placed horizontally opposite the eye. Now, I am no stickler for exact topography. The hills of Edderton and Tain are undoubtedly too long and bow-like in their curves. The Cromarty hills are certainly low and small. But I do venture to think that if the artist had used his invention in other ways—selecting his sky, and arranging his distant lights and shadows—he might have avoided the wholesale massacre of these innocents. There is a long shaft of haze, for example, thrown past the shoulder and along the side of the nearer hills from the west—like a faint golden ladder laid aslant—that has often seemed to relieve and dignify their humble outlines. I am aware that a certain license is claimed, and is always to be conceded. But it ought surely not to be used to the vile offending of the *genius loci*. If the respected artist was set on having points and peaks, where there are only curves and undulations, why not introduce boldly a real Alpine range, with its spires and domes and *dents* all shining in ivory and gold. Even at Dornoch the Alps may be said to be *in the distance*, accidentally obscured by the accident of earth-curvature and impurity of the air.

It may be hoped, however, that this maltreatment of individuality in mountain form is the last of an early phase in the development of landscape art, and a relic of the time when no landscape could command a price unless it could be described under a topographical title. We may pardon Turner if his Kilchurn Castle, with its plain round towers, would do almost as well for any other castle, or his Ben Cruachan for any other mountain. But we have now, thanks to him, a recognised school of imaginative landscape, and it is not too much to expect that if a picture is given out as topographical landscape that landscape it shall be.

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There is but one other subject to which I would briefly refer before passing on—namely, that of *contrasted* forms and colours in rocks, to which, as to the rest of the subject, I venture to think too little attention is given. An ideal of contrasted forms in rocks is perhaps to be found in Turner's Mount St Gothard in the "Liber Studiorum." Observe the easy dip of the rocks towards the left,—their downward cleavage, strong, steep, and decisive, in the precipice of the gorge; how the eye follows it down into the depths, and rises with it into the distant aiguilles and the heavenly aerial. Observe too how much depends, in the series of contrasts, upon the rounded form of the boulder at the roadside, which, by the way, seems to have been pushed aside in the making of the mountain road—it is too near the side to have fallen there. It is curious to notice—I am not sure whether the fact has escaped Mr Ruskin—that the strongest lines and strongest contrasts in Turner's mountain-drawing are exactly those that he might have studied—and doubtless did very carefully study—at home in London, in the interior of Westminster Abbey; the "perpendicular" of Nature, adding, loftiness to height and terror to depth, being the vertical cleavage and vertical stratification, the "pointed" Gothic—directing the eye upwards—being the cone of denudation in all stages of its refinement, from the pyramid to the needle; and the horizontal lines, with their suggestion, as Mr Ruskin has so often told us, of present repose and stability, being the plains, level banks, and terraces. In the Mount St Gothard we have all three, the horizontal, however, very subordinate.[1]

Contrasts in rock *colouring* I may safely leave with the artists, making but one remark. I do not see why rocks are so often represented as dead-grey and bleak, or brown and sombre, as if the world were made of carboniferous rocks and greywacke. Common stones, when they are wet—and how much does not all vivid colour in landscape in this country depend on moisture—have sometimes the richness of jewels; and I have seen a brilliance of almost vermilion colouring among the precipices of the North Sutor of Cromarty that reminded me of Blake, "the supreme painter of fire."

I now come to the third and last division of my subject—teachers and studies. It will not, I hope, be supposed that I arrogantly assume my *plea* to have been conceded. Who to learn from, what to study—these are questions I would not of myself have ventured to touch. But it is impossible to forget that an elaborate system of art teaching in geology has already

[1] Any reproduction of this water-colour that I have seen represent the original (which is preserved in the basement of the National Gallery) rather imperfectly.

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been given to us by one of the most exquisite writers of the age. What artist, with a taste for the artistic in literature, has not in his time drunk deep of the fountain of learning and delight that is to be found in the works of the great master of critical art and English prose to whom I refer? In the science of geology as ministering to art there has been, so far as I am aware, only this *one* teacher. It seems strange that Mr Ruskin should be a teacher in geology. You are aware of the eccentricity of his views on the subject. His "Deucalion" is almost comparable to Mr Ignatius Donelly's "Ragnarok, or the Age of Fire and Gravel," a production not unworthy of the author of the "Great Cryptogram," and yet, singular to relate, Mr Ruskin, in "Modern Painters"—though that great work was written from twenty to thirty years earlier than "Deucalion,"[1] and almost in the childhood of geology—has been preserved from serious error as if by nothing less than sheer genius and the direct inspiration of Nature. In his exposition of the artistic mountain form Mr Ruskin is, and probably will remain, without a rival. But whenever he quits his own proper ground, his geology, as might be expected, is hardly that science as known to the geologist. He does not even give us the poetry of the science as it was known forty years ago. He hardly seems to believe in or to realise the extreme antiquity of the earth.

Mr Ruskin's geology, moreover, suffers under two disadvantages. First, it is too much the geology of Turner, and, secondly, too much the geology of the Alps. The Turnerian geology is a kind of transcendental or transfigured geology. It is magnificent, and scientific, too, in its way, although he brings the Alps into England, and features of Yorkshire into the Alps, and is, of course, *sui generis*—a great constructive poet—everywhere. But it is surely impossible to recommend Turner's geology as a key to that of Nature.

As to Mr Ruskin's use of the Alps and Alpine geology, there is one cardinal objection to it—his teaching relates to a region remote from the study of our national school of painters. It is perhaps presumptuous to add that the Alps, although they furnish admirable examples of geological dissection, especially in cones of denudation (domes, spires, aiguilles, &c., determined by cleavage, foliation, and jointing), and of course the most tremendous precipices, do not readily lend themselves for the purposes of art, unless on the Turnerian or Dantesque scale. It is a fact which Mr Ruskin's plates are of themselves almost enough to prove, if that were necessary; and all the paintings I have seen, except those of Calame, serve to strengthen my impression of its truth.

[1] "Deucalion" was published in 1876.

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To some extent Mr Ruskin's geological work has the qualities both of Turner and of the Alps. It is of transcendent beauty, and rich in its teachings concerning mountain form; it may fill the minds of artists with the poetry of the mountains in all time coming; but it is certainly not the kind of teaching that helps the student to reason and understand. Mr Ruskin would be the first to admit that the mind cannot rest on externals; it demands imperiously to know the why and the wherefore of things. It demands reasons; and the best way to confuse a reasoning man is to present him with handfuls of loose facts which he cannot connect with one another or with their causes —like hieroglyphics without the reading. Mr Ruskin's own teaching—I say it emphatically—is a teaching that it requires some knowledge of geology properly to appreciate.

Let me repeat, then, that though Mr Ruskin gives us mountain form, and the *poetry* of mountain form almost in their perfection, it is not the form, and scarcely the poetry, of our Scottish mountains, nor is it in any broad sense the science of the mountains, nor the poetry of that science. The explanation of these two last facts, as might be expected, is given in his eccentric work "Deucalion." "It seems to me," he says, "that geology tells us nothing really interesting. It tells us much about a world that once was. But, for my part, a world that only once was is as little interesting as a world that only is to be. I no more care to hear of the forms of mountains that crumbled away a million of years ago to leave room for the town of Kendal" (the quotation is from a lecture delivered there) "than of forms of mountains that some future day may swallow up Kendal in the cracks of them." Now, I will not say that there is no truth in this. Mr Ruskin only accuses geology of a lack of human interest; and for my own part I do not expect any one to subsist upon the air of the past—even sympathetically—least of all the poet or the artist. But this statement, that "geology tells us nothing really interesting," is certainly fatal to Mr Ruskin's undivided authority as a teacher concerning a true understanding of the mountains and the poetry of the past in the present. Even his studies in mountain form will a little bewilder the student who is not already grounded in the science.[1]

For these reasons artists in landscape who care about the matter might do well to alternate their studies in Ruskin with sound study of other more recent and more catholic writers on

[1] I should do injustice to Mr Ruskin if I did not add that chap. xv. of his geological volume (vol. iv.) "On Crests," is the model of what descriptive writing of this kind ought to be. Eliminate only (or read in the light of more knowledge), 1st part, par. 7, and par. 20, second and third sentences.

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geology. The Scottish artist I would refer, first and foremost among the productions of living authors, to the "Scenery and Geology of Scotland" of Dr Archibald Geikie, one of the most polished writers on geology since Playfair. I name also Professor Green of Oxford,—his "Physical Geology for Students;" and Sir Andrew Ramsay,—his "Physical Geology of Great Britain." And perhaps I may permit myself to say that in my father's geological works he will find much—especially an ever present sense of the *wonder* of past time—that will help him to read a deeper meaning into Mr Ruskin's.

Let me add a word, lastly upon *studies*. I have thought carefully over the subject, but only to become more and more aware of my own inability to mark out *any* course of study in a case like this. If I had the fortune to be an artist, I believe I would endeavour to study geology on two sides—first, as the science of form and expression in mountains and rocks; secondly, as a poetic interpretation of past time. I would try to avoid mere technicality. Terms and classifications, no doubt, are indispensable, but they are only the floats, so to speak, by means of which we buoy up our knowledge to prevent it from sinking. But I would endeavour to cultivate what Sir Roderick Murchison used to call "an eye for a country." I would probably learn enough of "structure" to be able to run a general section across some bit of country where the rocks are prominent, so as thoroughly to understand the organic connection that exists between the rocks at the surface and the masses underneath; and then—I would never run another. I would probably do a little rock-dissection by means of skeleton sketches from Nature, taking Mr Ruskin's plate of the crest of the Bouchard (plate 34 in "Modern Painters," vol. iv.) as my model, and then I would never draw another diagram. I would learn enough, at any rate, to be able to interpret correctly the general impression mountains convey at a distance; and I would make the varying aspects and colouring of rocks the object of special studies—not forgetting that it is possible to find varying expression, and, so to speak, a different handwriting, or perhaps even hidden *cyphers*, in the same rock from day to day. Above all, and throughout all, I would endeavour to study geology at every point *as an exercise for the imagination*. If there were any kind of geological knowledge that, after sufficient trial, refused to take its place in the imagination, or to awaken any response there, I would discard it,—I should not deem it knowledge worth while my gaining.

And now I draw to a conclusion. I have tried to point the artist to geology, partly as a study that is closely in touch with

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his art, and partly as a study that is still in touch with the intellectual life of our time. If *he* will not learn from its teachings to add to his mental resources and the wealth of his imagination, I know not who can. There is something repellent to me in the *dictum* that the artist has to do only with the outsides of things. Expression, whether of the real or the ideal, can surely best be apprehended through a knowledge of the *nature* of things, as well as by a true and cultivated instinct.

There is, I am aware, one great school in art in modern days from which it seems to be claimed that *it*, at least, has need of no help from science—whether of geology or any other. I refer to the impressionist school. In mountain-drawing, for instance, impressionism presents us with outline and form, height and mass and distance, shadows and mist and snow; and truly it might seem at first sight as if artists of that school have learned all that they need to know. We are told that they give us "values" not details. I do not insist on the fact—true, so far as it goes—that the snowdrifts are shaped by the form of the hollows, and the mist by that of the valley and the hillside. But it does seem to me strange if men should propose to attain the maximum of ideality through the minimum of knowledge. I am aware that genius delights to appear to set at naught all rules; but I have been accustomed to think that he who would give us the *im*pression without the detail, has need most of all to gain the power of reading the *ex*pression; that you cannot idealise the thing you are ignorant of—succeeding, at best (if the attempt be made), in putting something else in its place. So long as the artist is willing to restrict himself to the superficies of things, his eye for form and colour, for effects and combinations of effects, is perhaps enough to serve his turn; but the moment he endeavours to give us real expression of character, he cannot, surely, do without some knowledge. I plead even with him for some judicious study of the *erdkunde* in this sense.

The great message of geology to the nineteenth century has already been delivered. Little more than fifty years ago the horizon of ordinary thinking men was bounded, as if by a wall, by a line drawn only six thousand years back in the past. The widening of that horizon to its true bounds was one of the greatest intellectual achievements of the century—perhaps of all time. No longer hemmed in by the wall of the Mosaic chronology,—part of that "wall of ordinances" that was to be broken down—we can lift our eyes to a distance so extreme, that we cannot in the dimness distinguish land from cloud, or sea from haze—the mind's eye losing itself, wondering, in the supreme firmament of God's eternity. I would fain have the painter, of

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whatever school he may be, more cognisant of that distance, as well as of much that lies nearer.

How extraordinary have not *his* contributions been to the civilising—I had almost said the spiritualising—of mankind! He shows us the shadow and the sunlight where they dance together under the trees; he shows us the motion of wind in cloud and smoke, and waving branches, and the maiden's floating hair; he gives to us the feeling and almost the music of the sound of the brook and of the church bells ringing across the fields; the ether of heaven he can make as if to send its vibrations sensibly to our vision; he gives to spirit form, and to poetry shapes; he shows us the soul of the man in his eyes; he gives to the meanness of human life mystery, and to its foulness tragedy. There is nothing on earth that shall be hid from him that the sun looks upon or the shadows rest upon. He will prove himself more and more, I am convinced, one of the vital powers in the higher education of coming generations. But I am fain that he should know more of the *ways* of Nature as he goes on

> "Striving to match the fingermark of Him
> The immeasurably matchless."

And I would fain point him to one door that up to the present he has allowed to remain closed, and ask him if he will not try to enter therein—into a region where there are other shadows, and a vast haze and vast silence—that he may come forth and, if it be possible, show us in new and exquisite ways things that we have not known concerning the poetry of the past and the truth that has been since the beginning. Then may he have power to give to the rocks more of their strength, more of their vast age, more also of their evanescence. He may show us something of the *secret* of the hills and the mystery which their depths embosom; and we shall, perhaps, see more clearly what at present we are able only to divine, that as Paul said to the Galatians concerning another matter—"These things *also* are an allegory."

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XX.—*The South-West Mayo and North-West Galway Silurian Basin, with Notes on the Old or Metamorphosed Rocks of West Galway.* By G. H. KINAHAN, M.R.I.A., &c., late of H.M. Geological Survey.

(Read 15th January 1891.)

PART I.—(ABSTRACT).

IN the summer of 1890, some officers of the Scottish Branch of the Geological Survey paid a ten days' visit to Galway with the object of reviewing the older rocks of that area by the light of knowledge they had recently gained in their study of the older Palæozoic and Archæan Rocks of the North-West of Scotland. The author of the present paper, who has spent many years in making a detailed survey of the Irish rocks in question, and who has had the further advantage of having examined the rocks of Sutherland, Ross, and Cromarty, under the guidance of his Scottish colleagues, fails to see his way to adopting a new reading of the stratigraphical relation of the Galway rocks which had been suggested. Part I. of the present communication contains a large number of arguments and facts bearing more or less upon the questions at issue, by which the author maintains that his own views are in the main correct.

After some preliminary observations upon the Laurentian, Huronian, and Potsdam rocks of North America, considered in relation to the oldest rocks of the British Isles, the author goes on to discuss in some detail the stratigraphical relation of the rocks composing the Killery basin, with especial reference to the evidence of unconformity between the rocks classed as Silurian in that basin and those which the author considers to be of Ordovician age.

The stratigraphical evidence adduced may be summarised as follows:—(1) The marked discordance between both the amount of dip and its direction in the newer (Silurian) series, as compared with the older (Ordovician). (2) The occurrence, in conglomerates near the base of the Silurians, of derived fragments, traceable to parent sources in the Ordovicians within a few miles. (3) The fact that many faults affecting the older rocks stop short at the boundary line of the Silurians. (4) The evidence of disturbance of the older rocks prior to the deposition of the Silurian. The author considers the cumulative evidence afforded by these structural features quite sufficient to warrant him in defending his older classification against the attacks that have been made upon it of late.

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In the section devoted to the palæontological evidence, the author is disposed to place reliance upon the fact that the fossils, upon which the separation of the Silurian rock from the Ordovician had originally been founded, were identified by Messrs Harkness, Bailey, King, and other reliable authorities acquainted not only with Irish fossils, but also with all the chief forms of the older Palæozoic fossils of Europe and America. The author considers that these authorities' opinion should be regarded in the present case as conclusive.

Part II.—The Granitic and Schistose Series of West Galway.

Introductory.

In the paper already mentioned (*Recent Researches into the Origin and Age of the Highlands of Scotland and the West of Ireland*), by A. Geikie, LL.D., &c., &c., Director-General of the Geological Survey of the United Kingdom,[1] occur the statements to which this paper refers. They will now be quoted in the order in which they occur—

Third Page, 544. "*Some years ago Mr Nolan mapped the rocks of North-East Tyrone as pre-Cambrian.*"

The last quotation, as it refers to a district outside of the area, the subject of the present enquiry may first be disposed of.

Mr Nolan, directed by Professor Hull, mapped, at the first, all the rocks of the Slieve Gallion district as Lower Silurians. (Ex. and map sheet 34, 1878.) In a paper read before the Royal Irish Academy in December 1879 I pointed out that the Lower Silurians of Messrs Hull and Nolan must be either Cambrian or pre-Cambrian. This classification of mine Professor Hull at first controverted, but after his Laurentian craze in 1881, he stated that the rocks were probably Laurentian, and in the explanation to accompany sheet 26, published in 1884, the statement is made that the rocks mapped by Mr Nolan as Lower Silurians are possibly pre-Cambrian.

During our stay in Sutherland, which was supplemented by a trip into Ross and Cromarty, we were shown some undoubted valuable discoveries, first made known by non-official geologists, and subsequently more minutely worked out by the officers of the Survey. We were asked to believe that the pre-Cambrian

[1] Proc. Roy. Instn. Gt. Britain, vol. xii. pt. iii. No. 82, p. 528 *et seq.*

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rocks were originally massive intrudes of Dioryte or allied rocks; and that their present apparent bedded structure is solely due to reconstruction; that is, attenuation caused by shearing, which obliterated the true bedding plane, and in their place substituted new ones. No positive proofs of these assertions were, however, forthcoming.

In the "Old Boy," there are masses and courses of the Hornblende rock (*Macculloch*), but now called a new name. These graduated into Nodular Hornblende rock, and the latter into Hornblendic schists. All of them have the appearance of intrudes with their mechanical adjuncts; similar to those in the counties Wexford, Waterford, and Wicklow, where the Ordovician whinstones and their adjuncts have the same general characters; although in these Irish localities the rocks have been subjected to very little metamorphic action, due to either shearing or molecular changes. Yet we were asked to believe, without proofs, that the order of succession, which can be ocularly proved in S.E. Ireland, had no representative in Sutherland, and that although in Ireland and Scotland the rocks are (practically speaking) identical, yet in Sutherland Macculloch's *Hornblende rocks* represent the untorn-up portions of the original mass of Dioryte; the *Nodular Hornblende rock* representing the partially torn-up portions, and the *Hornblendic schists* those parts that are fully torn-up. The advocates of this theory would, however, like to ignore that in all this area of "Old Boy" there are very considerable tracks that are highly quartzitic (*Micaceous or gneissose quartzyte*) and others very felspathic (*felsityte* and *micaceous felsityte*); rocks that by no shearing or by no molecular or no chemical changes, can be reconstructed Diorytes.

In the Sutherland, Ross, and Cromarty "Old Boy," similarly as in all other regions of metamorphic rocks that I have studied in the Old and New World, there are dykes more or less transverse and crossing the general stratification; and invariably in the dykes there is a foliation quite distinct from that in the associated country rocks. This to me seemed to be easily explained; because, as pointed out years ago by David Forbes, foliation was induced by the most prominent original structure; so here, in the country rocks, the foliation followed the original cleavage or lamination or other most pronounced structure, while in the dykes it followed their most prominent structures, which usually is more or less parallel to the walls of the dykes. Such simple explanations are not, however, allowed by the Shearers, as they insist that the foliation in the country rocks is due to a shearing force coming in one direction, while the foliation in the dykes is due to a shearing force coming subsequently in another;

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but they do not explain how the latter confined itself solely to the dykes, it very partially modifying the walls of the latter, they being now nearly as regular as when the dykes were first intruded.[1]

[1] The discoveries in connection with shearing in North Scotland are most valuable, but the observers seem to have tried to run before they could walk; as from their writings and statements they would seem to ask us to believe that foliation is solely due to shearing; this, however, cannot be so.

The granytes of the Lough Conn district, Co. Mayo, Ireland, has been changed by foliation into granitic gneiss, the whinstones into Hornblendic schists, and the sedimentary rocks into schist. Crossing all these rocks the strikes of the foliation are similar, while the dips are generally vertical or in one direction. The granitic gneiss occurs in large and small regular courses and as other intrudes in the schists; and these, as also the basic intrudes, invariably have their original boundaries intact; in places they are slightly serrated, but in no places are those intruded rocks pulled out into tongues, so as to make one rock be dove-tailed into the other, which ought to have been the case if the foliation had been introduced solely by shearing. The general character of the foliation suggests that all the rocks of this region, now metamorphosed, were at the first cleaved. It is well known that cleavage will invade a conglomerate, and cut through even hard quartz pebbles without changing their outlines; but if the same rock, either previous to or subsequent to cleavage, was affected by shearing, the inlying pebbles will be elongated and attenuated; these alterations being more regular in an uncleaved than a cleaved conglomerate, the change being greatest when the shearing has been in excess, or where it has been repeated on two or more different times. From these and other facts, it may be inferred that the foliation in rocks, in which the different boundaries are still intact or nearly so, is not the primary reconstruction of these rocks, but that it was induced by a previous reconstructor. In this and similar areas the first reconstruction of the rocks was probably due to cleavage, as in large areas it has the one style, but different dips in accordance with the nature of the rocks; also it leaves the boundaries of the different rocks intact or nearly so. As pointed out years ago in reference to the Hiar Connaught, or West Galway, where the majority of the sedimentary rocks were not originally cleaved, the foliation in them following other prominent structures in the original rocks.

After and during the shearing the rocks underwent molecular change, different minerals being leached out, and these leachings were piled on to the different leaves, thus giving an ordinary gneiss a granitic character; and if the shearing and molecular change was repeated over and over again, the granitic structure was increased more and more.

In the excessively-developed Norian gneiss of the Lake St John's district, Eastern Quebec, some of the mineral leaves are over a yard in length, yet the boundary between it and the associated Laurentians is nearly intact, so much that the original veins and squirts from these intrudes are still easily traced, although the rocks must have been subjected to different successive periods of metamorphism.

Metamorphism, due to molecular change induced by the cleavage planes, has misled many otherwise very careful observers, a remarkable instance being the pre-Cambrian rocks of the Black Hills, Dakota, U.S.A., where observer after observer mistook the foliation induced by the cleavage planes to be the true bedding; and a similar mistake has been made by different men in various places in Ireland.

Shearing, as proved in Scotland, acts somewhat similar to cleavage, but I see no reason for believing it can cause the effects that the Scottish geologists would have us to believe; as, undoubtedly, in some of the places where they say the bedded-like structure is due to shearing, it is not so; while in other places they will show you in certain rocks an incipient bedded-like structure

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From what I have learned elsewhere in metamorphic and sub-metamorphic territories, I am convinced that the general metamorphism of the Scottish "Old Boy," and that of its transverse dykes took place at one and the same time. That is, that the first general metamorphism of the area changed the country rocks into schists having one strike, and the dykes into schists having a transverse one. The regularity that has been preserved in the boundaries of the dykes ought to ocularly demonstrate this to every observer, unless he is so blinded by pre-conceived ideas that he is incapable of forming an unbiassed opinion.

Even in my forced hurried examination of the "Old Boy" of Sutherland, Ross, and Cromarty, I was able to see that in many places the foliation did not follow the ordinary parallel structures, said by my instructors to be due to shearing; but that in numerous places it varied considerably, and followed planes, such as naturally would be found, if in places the foliation had been induced by previous structure, such as oblique lamination, nodular structure, or some other well-developed character in the original rocks. Also in places on the surfaces of some of the so-called shearing planes there are markings, especially on some of the more quartzitic rocks, that are very like elongated ripple marks. My visit, however, was too brief to investigate them.

The so-called "eyes" in the Hornblendytes are said to be the untorn-up bits of the original Diorytes. The major portion of these eyes are of a similar class to the Hornblende rock masses. This even should be expected if, as I believe, these Hornblendytes with eyes were originally tuff or other mechanical adjuncts of the inlands. But some of the "eyes" are not so, they having a distinct foreign aspect, being felspathic and quartzitic. These also are accounted for by an assertion, that "they are portions of untorn-up veins in the Dioryte," yet in the mass such untorn-up veins cannot be shown. That such "eyes" should be elongated in a sheared rock is to be expected, as pebbles in sheared carboniferous conglomerates are elongated; while in some of the more ancient conglomerates the inlying blocks have been drawn out to great lengths.

As to the colouring of the schist round the eyes. This also should be expected; when we find in the different drift clay and fine sand deposited in curled laminæ round enclosed blocks. In places in the Silurian conglomerate some of the blocks are enveloped in shale, as recorded by Jukes. Perhaps it may be

due to shearing, but they totally fail in being able to show the rocks which would be the results of a complete tearing up by shearing of such rock, such as the tearing up of the Durness Limestone.

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allowable to suggest that geologists, before giving these sweeping determinations, would do well to examine the rocks of other countries as well as those in Scotland, especially what is to be seen in the Lake Superior district, North America, as there, to the south-west and west in the United States, and to the northward in the Dominions, they would learn that in places there are pre-Cambrian rocks exactly similar in characters to the "Old Boy," and that these, when traced for great distances into the United States, graduate into only slightly altered rocks. Also, they would learn that the foliation of the *more altered* rocks is not an entirely new structure; it having been induced more or less by former structures.

In support of their assertions these Scotch geologists specially pin their faith on the "Moine or Eastern schists." These schists undoubtedly are most remarkable rocks, but in connection with them, as with the "Old Boy," the Irish geologists were asked to believe more than could be proved.

The "Moine schists" are said to be torn-up "Old Boy," "Torridon Sandstone," "Pipe Quartzyte," and the "Durness Limestone."

We were shown in places the "Old Boy" passing into these schists; we were also shown the "Torridon Sandstone" passing into a schist very like the "Moine schists," while considerable portions of the "Moine schist" is a quartzose rock that possibly may originally have been the "Pipe quartzyte," while we were also shown the "Durness Limestone" becoming attenuated, but our instructors totally failed to show us in the "Moine schist" any rocks that possibly could be the representative of the torn-up portions of the Durness Limestone. We were told we could see it in the Loch Maree district, but when we went there this supposed torn-up limestone was evidently an intrude of calcareous whinstone.

Part III.—Abstract.

This part of the paper deals at some length with the field relation of the schists, gneisses, and granitic rocks of the Connemara district, chiefly with the object of showing that proof is wanting of the rocks in question being originally of igneous origin, in which a pseudo-stratified structure has been developed by dynamo-metamorphism.

The author states that in the Galway type of granitic rocks an imperceptible gradation from granite into gneiss, and even from gneiss into schist, can be traced in the field, and that the granitic rocks of this class in places occur in such a manner as

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to suggest that they are *newer* than the schists, and have been intruded amongst them.

In both Galway and Donegal the south margins of the granites show distinctly banded characters, being formed of bedded-like masses of distinct appearance and composition. A similar graduation occurs in S.E. Wexford, the granite passing into granitic gneiss, and this into alternation of gneiss and schist, which finally passes into schist alone. The rocks of S.W. Wexford, the writer has stated in former papers, are probably of Archæan age.

The author then proceeds as follows:—

"That the Galway rocks south of the Clifden and Oughterard road were once sedimentary is to me evident." The evidence in favour of this assertion will first be mentioned, and afterwards the reasons for supposing that they accumulated subsequent to the quartzytes of the Bennabeala (Twelve Pins).

To the north of the territory, in the neighbourhood of the lakes that extend from Clifden to Oughterard, there is a limestone and schist series with subordinate quartzytes (*Ballynahinch series*), in which the different sequences are so regular and can be traced for such long distances, although shoved backwards and forwards by numerous faults, that it is scarcely possible to believe their continuous relation one to the other can be due to anything but deposition. No attenuation due to shearing could give similar results; that is, no process of shearing, even if aided by molecular changes, could have separated out of an original mass of igneous rocks all the different constituents, and placed each as they are now found, in regular order. For miles each class of rocks have in the different sections the same relation to those above and below it. This could not possibly be due to shearing, while it is the order which should be induced by the previous stratification. This original order afterwards having been slightly modified by the shearing face, the similarity of the order, in each section, is the more conclusive, when we remember that the continuation of the original beds has received rough treatment, as these have been broken and shoved about by heaves, upthrust, and other faults.

In many of the original limestones there were cherty and shaly layers, while impurities were disseminated through them. All limestones, however, rapidly change, the change being so rapid that if we examine the plaster of an old house, or a barrel or sack of cement, which have been exposed to the weather, the changes which have taken place in them must be seen to be believed. In weathered plaster the constituents separate and give to it a spheroidal structure, or that structure combined with parallel lamination, while particles of the lime that had not

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properly disintegrated when the plaster was first put on, have caused settlements, which resemble, on a small scale, the faults in rock strata.

As to the barrels and sacks of cement, they may have been filled by the shovel or by a continuous supply from a shoot; but in either case, after they are filled, they are shaked up to consolidate the material, while subsequently, during carriage, they are again shaken up. During the construction of any large work some barrels or sacks will, through carelessness, become spoiled, and become consolidated into rock, which developes structures similar to those found in limestones. In the barrel filled by shovelling there are layers, each layer having a more or less spheroidal structure, due to the subsequent shaking, and in most cases there is a cleavage which cuts through both, due to the shrinkage. Sacked cement, as far as my experience goes, has only a spheroidal structure with only incipient lamination or cleavage. These peculiarities of plaster and "dead" cement have already been previously called attention to by myself and others, while, if I remember correctly, Mr A. B. Wynn was the first to draw attention some thirty years ago to the peculiar structure in old weathered plaster. In some ordinary limestones, but invariably in all highly metamorphosed limestones, similar structures are present. They, however, in the metamorphosed limestones have been more or less modified, on account of the vicissitudes the rocks afterwards were subjected to. In the natural limestones there are also the silicious and argillaceous layers and partings of the original accumulations, but any parting in old plaster or dead cement must be due to leaching out of the materials.

Such irregular structures in the metamorphic limestones are claimed to be the results of shearing and upthrusting. Both of these in most cases augmented them; but when similar structures occur in old plaster, in dead cement, and also in unaltered limestone, they should also be found in metamorphosed limestones. Also in the latter rocks they should be more conspicuous, as the leaching process should develop mica and other minerals along the structural lines; and the upthrusting would make the contortions more prominent, while the shearing in places would break up the continuity of the layers and partings, leaving the remains scattered about in the limestones, and having an appearance as if they were inlying pebbles of chert and mica schist, for which by some they have been mistaken.

In metamorphic limestones there are also nodules and lentils of granitic rocks, the endogenous granyte of Sterry Hunt. Some, however, have said that these nodules are inlying pebbles of granyte, and that the lentils are portions of veins

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of granyte, broken up by shearing. Such veins and nodules, however, have none of the characters of intrusive granytes; they evidently being pegmatytic or endogenous granyte.

Many of the metamorphosed limestones in the region south of the Clifden and Oughterard road have in them the above irregular structures and alterations, but a little north of the area, about a mile and a half north-east of Clifden, near Lough Cashleen, in very slightly altered limestones, there are cherty layers and nodules, similar to those found in the ordinary Silurian or Ordovician limestones.

The well-known Connemara Serpentine *(ophiolyte and ophicalcyte)*, all of which are found in the country to the north of the Clifden and Oughterard Valley, are said by Mr Peach to have been originally pickrytes or an allied rock. He may be correct, but if so, there were very complicated changes; the pickrytes first becoming dolomyte and dolomitic limestones, and subsequently having changed into the "Connemara Serpentine." The last change can be ocularly proved in different places, but especially in the Leisoughter marble quarry.

The tracts and courses of Dioryte and Hornblendyte, associated with the limestones of the Clifden and Oughterard Valley, but more largely developed in the schists of the country to the south, are stated to be untorn-up portions of the igneous rocks that originally occupied the entire area; these masses and courses having escaped the shearing and attenuation that tore up and reconstructed the associated rocks. Unfortunately for this theory, quartzytic limestone and felsytes, by no process of shearing, could be developed out of a Dioryte or allied rock; not even if the shearing was assisted by chemical and molecular changes. It may, however, now be stated that the quartzytes and felsytes were originally intrudes of felstone and quartz rock, that were also subsequently torn-up; but if so, how is it that no untorn-up portions of such rocks are now to be found, while considerable masses of the supposed untorn-up basic rock are numerous?[1]

The rocks of the Bennabeala and adjoining ranges are stated by me in previous writing to be the oldest in the region; because to the north, east, and south of them the Diorytes, Hornblendytes, and other groups of rocks occur on regular, similar, geological horizons. The Diorytes or Hornblendytes occur in masses and courses, and invariably interbedded with,

[1] In the ophytes (serpentines after igneous rocks) there are minerals that do not occur in the ophiolytes (serpentines after dolomytic and other calcareous sedimentary rocks). This is also the case in the Algonkian and Laurentian rocks of Quebec.

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or margining, or extending in continuation for miles, are schistose or nodular, or conglomeritic Hornblendic rocks.[1]

The nodular Hornblende rock, which often forms a continuation, but sometimes a margin to the masses, consists of larger or smaller blocks and pieces of it, generally in a Hornblendic schistose matrix, the latter apparently being the fine detritus derived from the weathering of the mass. In some places, however, the matrix may be a felsityte, a micalyte, or even a quartzyte, due to foreign materials being carried by driftage into the interstices between the blocks; while the conglomeritic schists, that extend from the nodular Hornblende rock, have an appearance as if they had originally been tuff or tuffose rock. But other conglomeritic schists are not so; they containing blocks and fragments of quartzyte, felstone and other rocks—the inliers (allowing for the changes due to metamorphism) being so similar to rocks in the Bennabeala range that I came to the conclusion that they had been derived from those rocks. In places these pebbly conglomerates change into a pebbly gneiss or even a granitic rock.[2]

If the schists of the region, as stated, are the results of the tearing up of a mass of Dioryte or allied rock, each untorn-up centre that still remains ought to graduate into the associated country rocks. This, however, is not so. The Dioryte centres, when the nodular varieties are present, always graduate into them; and the latter generally into tuffose rocks. But if the nodular varieties are absent, the Dioryte centres always have a hard boundary; while in many cases the nodular variety has the same between it and the country rock. These hard boundaries prove that such centres cannot be the residue of a mass; but that such were intrudes at a time later than the accumulation of the associated country rocks.

If we compare these metamorphosed traps and their adjuncts in Connemara with intrudes of unmetamorphosed traps and their adjuncts, let the latter be even of historic age, and we find similar relations to those in the metamorphosed rocks of Galway; but of the numerous records we may specially refer to the "Friction Breccia" of Colta, on the fragmentary adjuncts of our intrude; also to Admiral Smythe's graphic description of the

[1] The term *Hornblendyte* I orginally confined to Hornblende schist; Dana, however, extended it to include all Hornblendic rocks; and in a correspondence on the subject, he pointed out that this must be so, if the true petrological determination was to be followed, as in an intrude the margins would be schistose and the centre massive; so that the term if used as I proposed would be a lithological not a petrological classification.

[2] The published maps in regard to these rocks are confusing, as a l the conglomeritic rocks, whether tuffose or not, have been coloured and classed as one. In the country in the neighbourhood of Conga Lake the conglomeritic schists and gneiss on these maps are represented as tuffs.

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advance of a lava flow in Teneriffe, and Valentine Ball's descriptions and models of some of the Indian volcanoes; all such descriptions proving that schists of igneous rocks at their margins usually graduate into massive shingle. If such takes place in modern times, it ought also to have taken place in former times. That it did so can in Ireland be ocularly proved in the unaltered rocks of the counties Cork (*Devonian*), Limerick (*Carboniferous*), Waterford, Wexford, and Wicklow (*Ordovician*), and Antrim (*Eocene*), while in Wicklow and Wexford the unaltered rocks can be traced into the metamorphosed ones. Necessarily, however, in these older examples the nodular rocks are not the massive shingles now found margining the recent volcanic flows, as in all the older records the original shingles were subsequently subjected to aqueous action, that more or less knocked the shingle about, thereby rounding the blocks, while into the interstices between the blocks silt and other sediment or detritus was washed in and deposited.

The filling-in stuff, due to the currents generated by the blocks, had necessarily a more or less curled lamination, similar to that found circling round blocks in the drift, and in the still more recent river accumulations of the present time, more especially in those accompanying glacial rivers like those of the Canadian Rockies, where blocks are carried down on the ice in winter to be dropped into the wide river expanses during the "break up;" while subsequently, during the summer thaw, they are enveloped by beautifully curved laminæ of silt.

If this takes place in unmetamorphosed accumulations, such rocks when subjected to metamorphism ought to have similar characters; and to me it would appear more natural to suppose that the Hornblende schists with "eyes" (*supposed untorn-up portions of the normal rocks*) are representatives of the "Friction breccia" of Colta and the volcanic shingle of Admiral Smythe, while the eyes in the conglomeritic schists and gneiss were blocks in ordinary conglomerates, but necessarily in the metamorphosed rocks, the latter are more or less elongated by shearing or an allied force. The curling round the "eyes" (which has most ingeniously been proved (?) to be due to shearing) is evidently the modified curled structure found in all recent drift accumulations when blocks occur in fine water deposits. In what I was shown in Scotland I did not see proofs of the most important statements made and since published; while in Connemara there is ocular proof that similar statements made in connection with the rocks, cannot be correct, as in schistose or gneissose rocks, where many of the "eyes" are felstones, quartzyte, &c., such "eyes" cannot possibly be the "untorn-up" portions of a tract of Dioryte.

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It should be mentioned that at some of the Diorytic centres (such as that at Cashel Hill) the Diorytes and tuffose rocks are so interstratified and mixed up with the tuffose rocks that Jukes and others on seeing the Field maps, immediately stated, "these are evidently volcanic centres, the mapping being reproductions of the vertical sections of Teneriffe and other volcanoes."

The recent researches of the Americans have proved that formerly the arenaceous rocks were very erroneously classified; notwithstanding this, there are reasons for supposing that my old classification of the S.W. Mayo and N.W. Galway rocks are correct.

In the barony of Murrich, Co. Mayo, to the north of Killary Bay, the schists associated with the Corvockbeak Granyte Intrudes are evidently metamorphosed Silurians, as proved by the fossils in the unaltered portions, also that they overlie, unconformably the Doolough series (*Umalians*) is proved by these containing fragments of the rocks in the latter. This, however, is controverted by the Flying Scotchmen.

As to the whole series of the older metamorphic rocks. In previous writings, it is shown these are the lowest members of an anticlinal series in the neighbourhood of Steamstoun Bay, no similar rocks being found elsewhere; while to the northward, eastward, and southward of this Steamstoun series, there are apparently successive, conformable, sequences of similar groups of rocks.

However, as already suggested, such a sequence may be more apparent than real, similarly as in the contorted and folded rocks of the Lake Superior region; yet if so, it seems remarkable that everywhere that the older metamorphic rocks come out from under those belonging to the Silurian and the Carboniferous, the different groups are found in the same order; there being only one exception, which is the black graptolitic shale of the Slieve Portray District.

As the undoubted representatives of this have not positively been recognised elsewhere, it is unnecessary to again give my already published sections of the groups of rocks to the north-east and south of the Bennabeala anticlinal.

In conclusion, the probable ages of the metamorphic rocks of S.W. Mayo and N.W. Galway may be considered.

At one time, as in 1878, when the "Geology of Ireland" was published (*Kegan Paul & Co.*), a classification of these rocks appeared an easy task; now, however, it is not so, on account of the revelations due to the recent work of the American geologists. In the Lake Superior district, formerly the work of various eminent geologists seemed to prove that the metamorphosed rocks all belonged to one group; while now such a supposition

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is known to be incorrect, as these rocks belong to two or more widely separate groups, and although very similar in composition, in aspect, in strike, and in dip, yet they represent accumulations divided by greater or less intervals of time; each group having been upturned and denuded, and in places metamorphosed, prior to the latter group having accumulated, and that the present apparent conformability between these distinct groups is solely due to subsequent treatment; principally overthrusting and metamorphism, which has given to the re-arranged strata similar strikes and dips, and a more or less similar mineral composition and aspect.

Under these circumstances, it would be rash to make positive assertions in connection with the rocks of Mayo and Galway, more especially, as those *who have really carefully examined them* can point out, that in these regions there are phenomena very similar to some of those in the Lake Superior western district; also that some of the Irish rocks and their minerals are characteristic of the Algonkian of eastern Quebec and Vermont.

The eastern and western zone of the Lough Conga conglomeritic gneiss and schist is very similar to the conglomerate in the Marquetta district; and here as there, it may point to an unconformability; but if so, it undeniably proved that the rocks in the district to the south are of a later age to these to the northward in the Bennabeala group; as fragments of rocks from the latter are found in these conglomerates. These conglomeritic rocks, except that they have been more altered, are very similar to the conglomerate in the Croagh Patrick range, Co. Mayo; while both here and there, apparently above the conglomerates there are exotic rocks, the most marked difference being that, in the Croagh Patrick range, most of the exotic rocks have been altered into ophyte, while those above the Lough Conga conglomerate are not so.

It is also possible that under the Silurian basin of the Killeany Bay and Erriff Valley there may be a second unconformability, which would account for the older rocks north of that basin being less altered than those to the south of it. But against such a supposition there is the fact patent to any one really acquainted with the subject, that the metamorphic action in the whole of Ireland was greatest at centres or in lines; and that when such centres or lines are left, the alteration of the rocks may gradually diminish, to again increase as one of these centres or one of the lines is approached. This general rule, however, has in different localities to be modified, as the metamorphic action took place at different periods, often separated by long intervals of time; but the later overthrusting from the south-eastward has in nearly every portion of Ireland modified

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all previous actions, so that now the metamorphic rocks (of no matter what age) have, as to their present lie, very similar laws.

In favour of the Galway and Mayo rocks being of Archæan age there are those previously mentioned peculiar rocks so characteristic of the Algonkians of Eastern Quebec and Vermont. On account of the Silurian basin of the Killeany Bay breaking the direct connection between the intensely metamorphosed rocks of the Connemara region (*Connemarians*), and the less metamorphic rocks of S.W. Mayo (*Umalians*), when the age is positively proved; it cannot be stated for a certainty that the *Connemarians* are metamorphosed Ordovicians and Cambrians; but the reasons for supposing them to be so have been already given.

Summary.

In connection with the tract between the Killeany and Clew Bay, Co. Mayo, Mr Peach states—

1. All the rocks are of Silurian age. My *Umalians* (Croagh Patrick and Doolough Lewis) being sheared Silurians, so that consequently my boundary of the Creggaunbaun Silurian and my north boundary of the Killeany basin are myths.

2. The green slates in small exposures to the north of Killeany Bay, also them in Rossroe promontory are of Silurian not Ordovician age.

3. The fossil evidence used by me is valueless, as the fossils were wrongly determined.

4. The gneiss and schist north of Kilbride Bay, Lough Mark, are only a sheared portion of the fossiliferous Silurians to the northward.

1. The Silurians in the Creggaunbaun basin can be distinctly seen lying unconformably on the upturned associated *Umalians*, while in connection with the north boundary of the Silurian basin between Lough Mark on the east and the Atlantic on the west, the *Umalians* in various places can be seen striking at the Silurians; the latter always dipping southward at low angles (from nearly horizontal to 30° or 40°), while the Umalians are in places vertical. Also the conglomeritic and pebbly grits of the Silurians are more or less made up of fragments and the detritus of the *Umalians*.

In the *Umalians* there are numerous trap dykes and faults that come up to the boundary of the *Silurians*, but never enter them.

2. In the small patches of green slate north of the Killeany the dips are at high angles, often vertical, while the overlying Silurians dip north at from nearly horizontal to about 45°. The

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green slates in the Rossroe promontory are evidently brought up by a fault into conjunction with the Silurians to the southward, as can be seen when this fault is traced east into Slieve Partry.

3. The age and type of the Umalian fossils were determined by such authorities as Harkness, W. King, and Baily, after years of the study of Ordovician types, not only in Ireland but over the World.

4. The gneiss and schist north of Kilbride Bay, Lough Mark, are brought into their present position by a fault, probably an upthrust. The fossiliferous rocks to the northward are made up of their detritus. Also this tract is evidently a detached portion of the gneiss and schist area south of the bay, and the latter rocks can be ocularly proved to be covered unconformably by the Silurians.

In connection with the metamorphic rocks of north-west Galway (*Yarconnaught*), Dr A. Geikie's statements are not proven.

The rugged aspect intimated to be solely characteristic of the "most ancient regions of the world," is not a character, as so defined, it also occurring, nearly invariably, in all regions of metamorphic rocks of all ages, and also in regions of unmetamorphic rocks; while the aspects of the tracts of American Laurentians are quite tame when compared with some of the tracts of the Ontarians and Huronians.

A district 70 miles long, and over 20 miles wide, could not have been "most carefully examined" in less than ten days.

The *Connemarians* were not "most carefully examined," as the majority of the most important places were left unvisited.

The statements in connection with the Connemarians are rash, as in the conglomeritic gneiss and schists there are distinct proofs that the rocks were originally accumulations derived from the denudation of older strata.

The quartzytes in the schists, south of the Clifden and Oughterard road, evidently originally were sandstones; in some places the original fragments are intact.

Some of the argillaceous rocks, especially in the Archipelago north of Galway Bay, retain in a great measure their original sedimentary characters.

In at least one place, the limestone is scarcely changed, it containing the original chert layers and nodules.

The reasons for my former classifications of the strata cannot be changed; for if you go northward, eastward, or southward from the Bennabeala group of hills, you find in these directions very similar groups of strata, successively on each other.

On the other hand, however, the recent American work in the Lake Superior region points out how deceptive the arrangement

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of metamorphosed rocks in an entangled area may be; it is thus now inexpedient to be positive as to the classification of the groups of strata. Indeed, it is possible that there may be an unconformability concealed by the Killeany basin of Silurians; while the zone of the Lough Conga conglomerates may occur at the base of an inverted unconformability. The Umalians, however, by their fossils, are proved to be the equivalent of the Ordovician; while the Lough Conga conglomerate must be o later age than the rocks of the Bennabeala, as in it are found fragments of those rocks.

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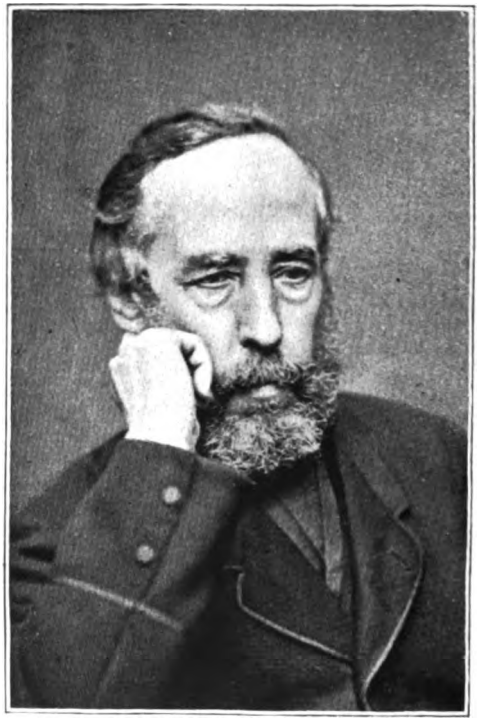

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XXI.—*Obituary Notice of Dr James Croll, F.R.S.* By J. HORNE, F.R.S.E., F.G.S., of H.M. Geological Survey of Scotland. [With Photograph.]

(Read 19th February 1891.)

SINCE the opening of the present session, this Society has lost one of its most distinguished Fellows, and the science of geology one of its devoted followers. As an original thinker and powerful investigator in that branch of geology relating to the physical cause of climatic change during geological epochs, Dr Croll was among the foremost, if not the first, of his time. He has left behind him a brilliant series of researches of which Scotchmen may well be proud. That he achieved so much without the advantages of special training in his early years, and in spite of a delicate frame, only serves to throw into relief his great intellectual strength and iron will.

Apart from his scientific researches, the story of his life may be briefly told. He was born at St Martin's, Perthshire, on the 21st January 1821, of parents of humble rank, who were devoted members of the Scotch Congregational Church. Following in early life the craft of a millwright, he was compelled to abandon it by an injury which he sustained. For a time he tried various occupations, with indifferent success. After years of patient waiting, he caught at last the flowing tide. By the kind intervention of the late Mr Walter Crum of Thornliebank, he obtained a situation at the Andersonian University, Glasgow—an appointment which proved a great boon to him. It gave him leisure to pursue those studies on electricity, heat, and the physical cause of climatic change, which formed the subjects of his earlier papers. It placed within his reach the University Library and the Library of the Philosophical Society; while the publication of his researches soon brought him into contact with one of the leaders of science in this country, Sir William Thomson.

But a better fate was yet in store for him. His papers on geological climate and glacial submergence naturally arrested the attention of geologists at home and abroad. The present Director-General of the Geological Survey, Dr A. Geikie, promptly recognised the value of these researches. Thanks to his administrative ability, Dr Croll was appointed secretary to the Scotch staff of the Geological Survey, when the Survey was reorganised in 1867. For fourteen years he discharged the duties of this office—a period of extraordinary intellectual

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activity in his career. During his term of service, no note of discord was ever heard from him. His rare modesty, combined with his great intellectual power, won the esteem of all his colleagues, who gladly placed at his disposal any fresh observations in the field bearing on glacial geology.

Eventually the prolonged intellectual strain told on his health, which was never very robust. Serious symptoms supervened in 1881, which compelled him to sever his connection with the Survey. But, though invalided, he was not vanquished. By watchful care, he so husbanded his strength, that he was able at intervals to pursue his favourite researches for a further period of nine years. A friend who visited him during his last illness says, that his powerful mind remained clear and eager to the last, revolving thoughts on favourite themes which his feeble voice could hardly utter. On the 15th of December 1890 he passed away, at the age of sixty-nine.

Turning now to his long series of contributions to science and metaphysics, it will hardly be possible, within the limits of this notice, to do more than give a brief summary of his more important researches, laying special emphasis on those on which his reputation will ultimately rest.

His first work, entitled "The Philosophy of Theism," published in 1857, at the age of thirty-six, endeavoured to define the relation of Theism to the determination of molecular motion. He tried to show that, for the production of any organism, two things are necessary—(first) motion; (second) the determination of motion. Mere vital force might account for motion, but the determination of motion implies an idea, design, and a directing mind.

The publication of "The Philosophy of Theism" plainly showed the philosophical bent of his mind, and his early metaphysical bias. But, after his removal to Glasgow, he turned his attention to scientific subjects. In 1861, at the age of forty, appeared his first scientific paper on "Ampere's Experiment on the Repulsion of a Rectilinear Electrical Current on Itself." From this date till his retirement from the Geological Survey—a period of twenty years—he published nearly eighty papers, extending over a wide range of subjects. The titles of his earlier communications, prior to 1864, show the varied character and abstruse nature of his researches, including, amongst others, the following:—"Chemical Combination in Relation to Specific Heat;" "The Cohesion of Gases;" "The Mechanical Power of Electro-Magnetism;" "The Relation of Chemical Affinity to Vital Force."

In 1864, however, he published a remarkable paper "On the Physical Cause of the Change of Climate during Geological

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Epochs," which formed the starting-point for a brilliant series of investigations extending over many years. In connection with this memoir, it is interesting to recall the views then held in this country regarding the phenomena of the Glacial Period. Notwithstanding the highly suggestive paper of Agassiz in 1840, in which he showed how the *roches moutonnées*, striations, and glacial deposits, indicate the former existence of land-ice in Scotland, geologists were slow in accepting his opinions. For years nearly every geologist in Britain clung resolutely to the theory of the iceberg origin of the drift. At length it was vigorously assailed by Professor Ramsay, Dr Archibald Geikie, and Mr Robert Chambers. From a careful examination of the evidences of ice-action in this country, Canada, and the Continent, Ramsay felt convinced that the theory was no longer tenable. In like manner, Dr Archibald Geikie, who in his early years had accepted the old explanation, was compelled to abandon it in 1861, after an extended series of observations in different parts of Scotland. He prepared an elaborate memoir on the subject, giving a detailed description of the phenomena, and his reasons for attributing them to the action of land-ice. While this memoir was in preparation, another eminent Scotch glacialist, Mr Jamieson of Ellon, arrived at similar conclusions from his own independent observations, and Sir Charles Lyell also adopted the same explanation.

Dr A. Geikie's paper was read in abstract to the Geological Society of Glasgow in 1862, and published as a separate memoir in 1863, appearing subsequently in the first volume of the *Transactions*. When we consider the date of publication of this elaborate memoir, nearly 200 pages in length, geologists will readily admit that it is of special importance in connection with the history of glacial geology in Britain. There can be little doubt that it paved the way for the final rejection of the iceberg hypothesis in this country.

The cogent arguments advanced by Dr A. Geikie in favour of the former existence of land-ice in Scotland had doubtless a powerful influence on Croll's philosophic mind. He evidently realised that the iceberg theory was doomed, and that well-nigh twenty years had been lost by geologists in this country owing to their stubborn refusal to adopt the suggestions of Agassiz. Accepting the land-ice origin of the boulder clay and moraines, Croll proceeded, with characteristic boldness, to grapple with the question of the probable cause of climatic change. To a man of his originality and power, the existence of glacial conditions in temperate latitudes during former geological epochs must have been a problem of absorbing interest. Various theories have been advanced to account for such alternations of

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climate. Some have suggested that they might be due to a change in the position of the earth's axis of rotation; others, that the earth may have passed through hot and cold regions of space, while Sir Charles Lyell strenuously advocated the doctrine that they may have been caused by changes in the distribution of land and sea, on the assumption that elevation of land about the poles would lower the temperature of the globe, and that elevation round the equator would raise it. Recent researches, however, are rather opposed to the belief in such enormous terrestrial changes, and seem to point to the permanence of continental and oceanic areas from primeval time.

Owing to an early suggestion of Sir John Herschell, the attention of geologists was directed to the probable effect of cosmical causes in producing climatic change. In 1830, he showed that during a period of high eccentricity, the hemisphere, whose winter occurs in Aphelion, will experience a long and exceptionally cold winter and a hot summer; while the opposite hemisphere will enjoy equable climatic conditions. But he subsequently held that the cold of the glacial period could hardly be due to the direct effects of high eccentricity, because each hemisphere must receive precisely the same amount of heat; and further, the deficiency of heat resulting from the sun's greater distance would be equalised by the excess of heat received during the short but hot summer.

To Dr Croll belongs the rare merit of showing that, though glacial cycles may not arise *directly* from cosmical causes, they may do so *indirectly*. As already indicated, his first contribution to the subject was published in 1864, but the development of his theory resulted in a series of brilliant researches extending over a period of eleven years, to 1875. He was led to investigate the problem of the eccentricity of the earth's orbit and its physical relations to the glacial period. By means of Leverrier's formulæ, he calculated tables of eccentricity for three million years in the past and one million years in the future, with the view of determining the periods of high eccentricity which, according to his theory, were coincident with cycles of extreme cold.

He was further led to consider the various physical agencies affecting climate resulting from periods of high eccentricity, of which by far the most important is the deflection of ocean currents. In connection with this question he called attention to the influence of the Gulf Stream as an agent in the distribution of heat on the surface of the globe. He pointed out that the quantity of heat transferred by the Gulf Stream from equatorial regions into the North Atlantic is enormously greater than was previously imagined, amounting to no less than one-fifth part of the entire heat possessed by the North Atlantic.

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He contended that, "to such an extent is the temperature of the equatorial regions lowered, and that of high temperate and polar regions raised, by means of ocean currents, that were they to cease, and each latitude to depend solely on the heat received directly from the sun, only a very small portion of the globe would be habitable by the present order of beings." It is obvious, therefore, that if from any cause the Gulf Stream were deflected into the Southern Ocean, the temperature of the northern hemisphere would be greatly lowered.

These latter researches led him to enquire into the physical cause of ocean currents, which proved the most difficult and perplexing part of his investigations. Two theories had been advanced to account for oceanic circulation—viz., the gravitation theory and the wind theory. He controverted that form of the gravitation theory advocated by Lieutenant Maury, who ascribed the currents of the ocean to difference of specific gravity resulting from difference of temperature between the sea in equatorial and polar regions. He also keenly opposed the phase of the gravitation theory expounded by Dr Carpenter, who maintained that difference of temperature between the sea in equatorial and polar regions produces a general movement of the upper portion of the sea from the equator to the poles and a counter movement of the under portion from the poles to the equator. On the other hand, he contended that ocean currents are caused and maintained, not by the impulse of the trade winds alone, but of the prevailing winds of the globe regarded as a general system.

These various lines of research are intimately associated with the fundamental question of the physical cause of climatic change.

As Dr Croll's reputation as an original thinker will ultimately rest on these luminous memoirs, which, with other researches, were eventually published in one volume, entitled "Climate and Time," in 1875, a brief statement of his theory may here be given as presented in Chap. IV. of that volume.

With the eccentricity at its superior limit, and the winter occurring in Aphelion, the earth would be about eight millions of miles farther from the sun than at present. The reduction in the amount of heat received from the sun owing to his increased distance would lower the mid-winter temperature to an enormous extent. In temperate regions, the greater part of the moisture of the air is at present precipitated in the form of rain, and the small portion, which falls as snow, rapidly disappears. But in the foregoing circumstances, the mean winter temperature would be lowered so much below the freezing point that what now falls as rain would then fall as snow. But the winters

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would then not only be colder than now, they would also be much longer. At present the winters are nearly eight days shorter than the summers, but with the eccentricity at its superior limit, and the winter solstice in Aphelion, the length of the winters would exceed that of the summers by thirty-six days. The lowering of the temperature and the lengthening of the winter would both tend to increase the amount of snow accumulated during the winter. The result would be, that at the commencement of the short summer, the ground would be covered with the winter's accumulation of snow. The presence of so much snow would lower the summer temperature, and prevent to a great extent the melting of the snow.

There are three ways by which accumulated masses of snow and ice tend to lower the summer temperature.

First. By means of direct radiation.

Second. Because the rays, falling on snow and ice, are to a great extent reflected back into space. Those that are not reflected, but absorbed, do not raise the temperature, as they disappear in the mechanical work of melting the ice. Whatever may be the intensity of the sun's heat, the surface of the ground will be kept at 32° so long as the snow and ice remain unmelted.

Third. Snow and ice lower the temperature by chilling the air and condensing the vapour into thick fogs. The great strength of the sun's rays during summer, due to his nearness at that season, would tend to produce an increased amount of evaporation. But the presence of snow-clad mountains and an icy season would chill the atmosphere, and condense the vapour into thick fogs. The thick fogs and cloudy sky would effectually prevent the sun's rays from reaching the earth, and the snow in consequence would remain unmelted during the entire summer.

But the cause which, above all others, tends to produc changes of climate is the deflection of ocean currents. A high condition of eccentricity produces an accumulation of snow and ice on the hemisphere whose winter occurs in Aphelion. This accumulation tends in turn to lower the summer temperature, to cut off the sun's rays, and so to retard the melting of the snow. It tends to produce on that hemisphere a state of glaciation. But on the other hemisphere, which has the winter in Perihelion, opposite effects take place. There the shortness of the winters, and the increase of temperature owing to the proximity of the sun, combine to prevent the accumulation of snow. The general result is that the one hemisphere is cooled, and the other heated. This state of things now brings into play those agencies which tend to the deflection of the Gulf

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Stream. When the northern hemisphere is being glaciated the north-east trade winds of this hemisphere will far exceed in strength the south-east trade winds of the southern hemisphere. The median line between the trades will lie considerably to the south of the equator. The effect of the northern trades blowing across the equator to a great distance will be to impel the warm water of the tropics over into the southern ocean. By this means the Gulf Stream would be deflected to the south of Cape St Roque, and would flow along the Brazilian coast into the southern ocean. The deflection of the Gulf Stream, combined with the other causes already mentioned, would, according to Dr Croll, place Europe under glacial conditions, while the temperature of the southern ocean would be enormously raised. He shows that but for the Gulf Stream and other currents, London would have a mean annual temperature, 40° lower than at present.

Such is a brief outline of Croll's ingenious method of explaining the occurrence of an Arctic climate in temperate latitudes in former geological epochs. In support of his theory he appealed with confidence to the evidence in favour of warm interglacial periods, which he regarded as a crucial test. Reviewing the data which had been gradually accumulated by geologists in favour of the belief that the ice-age was not an epoch of continuous cold, but consisted of a succession of cold and warm periods, he contended that this sequence follows as a necessary consequence from his theory of secular changes of climate.

But in addition to the luminous memoirs bearing on the foregoing theory, Dr Croll pursued other lines of research, the results of which were published in various periodicals, and subsequently incorporated in his volume on *Climate and Time*. In the *Philosophical Magazine* for 1850 Mr Alfred Tylor published a paper in which he estimated the amount of sediment brought into the ocean by denuding agents. He inferred that one foot removed off the general surface of the land during that period would raise the sea level three inches. At a later date Croll approached this question, and pointed out that the rate at which the materials are carried off the land is measured by the rate at which sediment is carried down by our river systems. Hence, in order to determine the present rate of subaerial denudation, we have only to ascertain the quantity of sediment annually carried down by the river systems. From the estimates of the materials discharged by the Mississippi, furnished by Humphreys and Abbot, he inferred, in 1868, that the rate of denudation is about one foot in six thousand years. Taking the mean elevation of the land, given by Humboldt at 1000 feet, he con-

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tended that the whole would be carried down into the ocean by our river systems in about six million years, if no elevation of the land took place. He further showed the value of this method as a measure of geological time.

Another ingenious investigation relates to the displacement of the earth's centre of gravity by a Polar ice-cap, resulting in submergence. This suggestion was first advanced by M. Adhemar in his work *Revolutions de la Mer* in 1842, but when Croll published his views on the subject in the *Reader*, he was unaware of Adhemar's conclusions. In connection with this question Croll estimated the probable thickness of the Antarctic ice-cap, and computed the rise in the level of the ocean, resulting from the transfer of an ice-cap two miles thick from the southern to the northern hemisphere. According to the method which postulates the rise at the pole to be equal to the extent of the displacement of the earth's centre of gravity, he inferred that the rise at the North Pole would be about 380 feet, and the rise in the latitude of Edinburgh would be 312 feet. By this means he endeavoured to account for the submergence during the glacial period, instead of ascribing it to a subsidence of the land.

Following up the idea of the existence of Continental ice-sheets during the glacial period, he was the first to suggest that the Scandinavian and Scotch ice-sheets coalesced on the floor of the North sea, moving westwards towards the Atlantic, thereby accounting for the marine shells and boulders of Secondary rocks in the Caithness boulder clay.

In connection with the movement of Continental ice-sheets and glaciers, he was led to investigate that perplexing question in physics, viz., the physical cause of glacier motion. He reviewed the various theories which had been advanced to explain this phenomenon, indicating various objections to them. He ultimately advanced an ingenious explanation of his own, which may here be briefly summarised from his statement of the theory in *Climate and Time*.

Ice is not absolutely solid throughout. It is composed of crystalline particles which are not packed so closely together as to include interstices. They are united to one another at special points determined by their polarity, and on this account they require more space. It will be obvious, then, that when a crystalline molecule melts, it will not merely descend by gravitation, but capillary attraction will cause it to flow into the interstices between the adjoining molecules. The moment that it parts with the heat received it will of course resolidify, but it will not solidify so as to fit the cavity which it occupied in the fluid state. For the liquid molecule in solidifying assumes the

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crystalline form, and of course there will be a definite proportion between the length, breadth, and thickness of the crystal; consequently it will always happen that the interstice in which it solidifies will be too narrow to contain it. The result will be that the fluid molecule in passing into the crystalline form will press the two adjoining molecules aside in order to make sufficient room for itself between them. The crystal will not form to suit the cavity, the cavity must be made to contain the crystal. And what holds true of one molecule holds true of every molecule which melts and resolidifies. This process is therefore going on incessantly in every part of the glacier, and in proportion to the amount of heat which the glacier is receiving. This internal molecular pressure, resulting from the solidifying of the fluid molecules in the interstices of the ice, acts in the mass of the ice as an expansive force tending to cause the glacier to widen out in all directions.

The lateral expansion of the ice from internal molecular pressure, according to Dr. Croll, explains how rock basins may be excavated by means of land ice. It also removes the difficulties experienced in accounting for the movement of ice up a steep slope. Nay, further, he called attention to the fact that the ice which passed over Strathmore must have been over 2000 feet in thickness. An ice-sheet 2000 feet thick exerts a pressure on the rocky floor of upwards of 51 tons per square foot. When we reflect, he contended, that ice under such enormous pressure, with grinding materials lying underneath, was forced by irresistible molecular energy up an incline of one in seven, it is not at all surprising that the hard lava should be ground down and striated. It also helps us to realise how the softer portions of the rocky surface over which the ice moved should have been excavated into hollow basins.

The speculations of physicists regarding the limit of geological time prompted him to investigate the question of the probable age and origin of the sun. Accepting gravitation as the only conceivable source of the sun's heat, he reviewed the two forms in which this theory had been presented, first, the meteoric theory advocated by Meyer, and, second, the contraction theory, expounded by Helmholtz. Even if we postulate 100 millions of years as the limit of geological time, he maintained that gravitation will not account for the supply of the sun's heat during so long a period. According to the foregoing theories, it is assumed that the matter composing the sun, when it existed in space as a nebulous mass, was not originally possessed of temperature, but that the temperature was developed as the mass condensed under the force of gravitation. He suggested that the nebulous mass might have been possessed of an original store of

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heat previous to condensation. Proceeding to consider how the sun's mass could have become possessed of energy in the form of heat previous to condensation, he argued that it was readily explained by means of the dynamical theory of heat. "Two bodies, each one half the mass of the sun, moving directly towards each other with a velocity of 476 miles per second, would by their concussion generate in a single moment the 50,000,000 years' heat." He further contended that we are led from physical considerations regarding the age of the sun's heat to the conclusion that the geological history of our globe must be limited to 100 millions of years.

His great work, *Climate and Time*, embodying the foregoing researches which appeared in 1875, produced a profound impression on Geologists at home and abroad. His opponents, as well as those who adopted his opinions, admired the originality and philosophic grasp displayed by the author. Hardly eleven years had elapsed since the publication of his first paper bearing on the physical cause of climatic changes, and yet, quite a revolution had taken place in the method of interpreting glacial phenomena. The marvellous development of opinion regarding glacial questions had been signalised by the publication of Professor James Geikie's epoch-making volume, *The Great Ice-Age*, in 1874. The views so ably expounded by these authors regarding the former extension of land-ice in the northern hemisphere during the glacial period, have been generally accepted and now form part of the common stock of geological knowledge all over the world.

But the theory developed by Dr. Croll of the physical causes of secular changes of climate, and the researches on which that theory was based, gave rise to prolonged controversy. Though one of the most modest of men, he was a keen controversialist. The numerous replies to his antagonists appeared chiefly in the pages of *Nature* and the *Philosophical Magazine*. They were subsequently collected and published in 1885 in *Climate and Cosmology*, which is to a large extent a further development of his previous work. In 1889 he published a volume on *Stellar Evolution*, in which he states the geological argument against the views held by Thomson and Tait, regarding the age of the sun.

The few remaining months of his life were devoted to a wholly different field of enquiry. He reverted to those philosophical questions which had fascinated him in his early years. In his last work, *The Philosophical Basis of Evolution*, which issued from the press about three months before his death, he contended that evolution by force was impossible. He maintained that the production of motion and the determination of motion,

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the production of force and the determination of force, are absolutely and essentially different. Reviewing the theory of development advocated by Darwin and Spencer, he associates the phenomena of evolution with this continuous direction of motion, which to his mind betoken will and purpose. To those who enjoyed his friendship, he occasionally referred to this question in terms which plainly indicated that he did not halt between two opinions. The idea that a Supreme Will directed the course of Nature was the cardinal point in his faith.

Of his private life it may be truly said that "whatever record leaps to light, he never shall be shamed;" of his career as a man of science it may be confidently asserted that he has nobly sustained the reputation of the Scottish School of Geology, which was founded by the genius of Hutton and Hall.

List of Scientific Papers and Works. By JAMES CROLL, LL.D., F.R.S., Formerly of H.M. Geological Survey of Scotland.

1857.

1. The Philosophy of Theism. London: Ward & Co.

1861.

2. Remarks on Ampere's Experiment on the Repulsion of a Rectilinear Electrical Current on itself. *Philosophical Magazine*, April 1861.

1862.

3. On Chemical Combination in relation to Specific Heat. Read before the Chemical Society, March 6, 1862. *Chemical News*, March 8, 1862.
4. Remarks on Ampere's Experiment on the Repulsion of a Rectilinear Current on itself. *Philosophical Magazine*, May 1862.
5. On the Cohesion of Gases, and its relations to recent experiments on the Thermal Effects of Elastic Fluids in Motion. *British Association Report*, 1862, p. 21 (Sections).
6. On the Mechanical Power of Electro Magnetism. *British Association Report*, 1862, p. 24 (Sections).
7. Amperian Repulsion. *Philosophical Magazine*, Oct. 1862.

1863.

8. On the Relation of Chemical Affinity to Vital Force. *Chemical News*, May 16, 1863.

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1864.

9. On Supposed Objections to the Dynamical Theory of Heat. *Philosophical Magazine*, March 1864.
10. On the Influence of the Tidal Wave on the Earth's Rotation, and on the Acceleration of the Moon's Mean Motion. *Philosophical Magazine*, April 1864.
11. On the Nature of Heat Vibrations. *Philosophical Magazine*, May 1864.
12. On the Cause of the Cooling Effects produced on Solids by Tension. *Philosophical Magazine*, May 1864.
13. On the Physical Cause of the Change of Climate during Geological Epochs. *Philosophical Magazine*, August 1864.

1865.

14. On the Physical Cause of the Submergence of the Land during the Glacial Epoch. *The Reader*, Sept. 2, 1865. *Natural History Review*, 1865, p. 594.
15. On the Submergence of the Land. *The Reader*, Oct. 14, 1865.
    With first suggestion as to the Invasion of the North Sea by Land-Ice during the Glacial Epoch.
16. On Glacial Submergence. *The Reader*, December 2 and 9, 1865.

1866.

17. On the Eccentricity of the Earth's Orbit. *Philosophical Magazine*, Jan. 1866.
18. Glacial Submergence on the Supposition that the Interior of the Globe is in a Fluid Condition. *Reader*, Jan. 13, 1866.
19. Glacial Submergence. *The Reader*, March 3 and 26, 1866.
20. On the Physical Cause of the Submergence and Emergence of the Land during the Glacial Epoch, with a note by Prof. Sir Wm. Thomson. *Philosophical Magazine*, April 1866.
21. On the Influence of the Tidal Wave on the Motion of the Moon. *Philosophical Magazine*, Aug. and Nov. 1866.
22. On the Reason why the Change of Climate in Canada since the Glacial Epoch has been less complete than in Scotland. *Transactions of the Geological Society of Glasgow*, 1866.

1867.

23. On the Eccentricity of the Earth's Orbit and its Physical Relations to the Glacial Epoch. *Philosophical Magazine*, February 1867.

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24. On the Reason why the Difference of Reading between a Thermometer exposed to Direct Sunshine and one Shaded diminishes as we ascend in the Atmosphere. *Philosophical Magazine*, March 1867.
25. On the Change in the Obliquity of the Ecliptic; its Influence on the Climate of the Polar Regions and Level of the Sea. *Transactions of the Geological Society of Glasgow*, Vol. II., p. 177. *Philosophical Magazine*, June 1867.
26. Remarks on the Change in the Obliquity of the Ecliptic and its Influence on Climate. *Philosophical Magazine*, Aug. 1867.
27. On certain Hypothetical Elements in the Theory of Gravitation, and generally received Conceptions regarding the Constitution of Matter. *Philosophical Magazine*, Dec. 1867.

1868.

28. On Geological Time, Part I. Method of Determining the Rate of Sub-aerial Denudation. *Philosophical Magazine*, May 1868.
29. On Geological Time, Part II. Tables of Eccentricity of the Earth's Orbit. *Philosophical Magazine*, Aug. 1868.
30. On Geological Time, Part III. Inquiry into the Effects of Icebergs, Inter-glacial periods, &c. *Philosophical Magazine*, Nov. 1868.

    With the Suggestion that the Warm and Cold Periods of the Glacial Epoch explain the commingling of Mammalia of Sub-tropical and Arctic Types in the Cave and River Deposits.

1869.

31. On the Physical Cause of the Motions of Glaciers. *Philosophical Magazine*, March 1869. *Scientific Opinion*, April 14, 1869.
32. On the Influence of the Gulf Stream. *Geological Magazine*, April 1869. *Scientific Opinion*, April 21 and 28, 1869.
33. On Mr Murphy's Theory of the Cause of the Glacial Climate. *Geological Magazine*, Aug. 1869. *Scientific Opinion*, Sept 1, 1869.
34. On the Opinion that the Southern Hemisphere loses by Radiation more heat than the Northern, and the supposed Influence that this has on Climate. *Philosophical Magazine*, Sept. 1869. *Scientific Opinion*, Sept. 29, Oct. 6, 1869.
35. On Two River Channels (between Forth and Clyde) buried under Drift belonging to a Period when the Land stood several hundred feet higher than at present. *Transactions of the Geological Society, Edinburgh*, Vol. I., p. 330.

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1870.

36. On Ocean Currents, Part I. Ocean Currents in relation to the Distribution of Heat over the Globe. *Philosophical Magazine*, Feb. 1870.
37. On Ocean Currents, Part II. Ocean Currents in relation to the Physical Theory of Secular Changes of Climate. *Philosophical Magazine*, March 1870.
38. On the Path of the Ice-Sheet in North-Western Europe and its relations to the Boulder-Clay of Caithness. *Geological Magazine*, May and June 1870.
    Reprinted, with a slight rearrangement of paragraphs, in '*Climate and Time*,' chap. xxvii.
39. On the Cause of the Motion of Glaciers. *Philosophical Magazine*, Sept. 1870. Short abstract by Editor in *Geological Magazine*, Dec. 1870.
40. On Ocean Currents, Part III. On the Physical Cause of Ocean Currents—Examination of Lieut. Maury's Theory. *Philosophical Magazine*, Oct. 1870.

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41. On the Transport of the Wastdale Granite Blocks. *Geological Magazine*, January 1871.
42. On a Method of Determining the Mean Thickness of the Sedimentary Rocks of the Globe. *Geological Magazine*, March 1871.
43. Mean Thickness of the Sedimentary Rocks. *Geological Magazine*, June 1871.
44. On the Age of the Earth as determined from Tidal Retardation. *Nature*, Aug. 24, 1871. *English Mechanic*, Sept. 1, 1871.
45. Ocean Currents: On the Physical Cause of Ocean Currents. Examination of Dr Carpenter's Theory. *Philosophical Magazine*, Oct. 1871.

1872.

46. Ocean Currents. *Nature*, Jan. 11, 1872.
47. Ocean Currents: Reply to Mr Ferrel. *Nature*, March 21, 1872.
48. Ocean Currents: Proof that Ocean Currents are not due to Gravity. *Nature*, April 25, 1872.
49. Ocean Currents: Reply to Mr Ferrel. *Nature*, July 25, 1872.
50. What Determines Molecular Motion?—The Fundamental Problem of Nature. *Philosophical Magazine*, July 1872.
51. Kinetic Energy. *Nature*, Aug. 15, 1872.
52. Oceanic Circulation: Reply to Prof. Everett and Mr Wallace. *Nature*, Oct. 3, 1872.

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1874.

53. Ocean Currents: Further Examination of Gravitation Theory. *Philosophical Magazine*, February 1874.
54. Ocean Currents: The Wind Theory of Oceanic Circulation. *Philosophical Magazine*, March 1874.
55. Ocean Currents: Reply to Dr Carpenter. *Nature*, May 21, 1874.
56. On the South of England Ice Sheet. *Geological Magazine*, June 1874.
57. The Physical Cause of Ocean Currents. *Philosophical Magazine*, June 1874. *American Journal of Science and Arts*, September 1874, p. 228.
58. On the Physical Cause of the Submergence and Emergence of the Land during the Glacial Epoch. *Geological Magazine*, July and August 1874.

1875.

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* The list of Dr Croll's scientific publications from 1861 to 1883 was prepared at the latter date for a special purpose. I am indebted to the kindly aid of Mr Bennie of the Geological Survey of Scotland for completing the list.

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XXII.—*An Outlier or Minor Basin of Old Red Sandstone in Mid-Ross-shire.* By Mr Wm. Morrison, M.A.

(Read 19 February 1891.)

Geographical Position.

The Mountain mass of Ben Wyvis is the most prominent object in the landscape to the north of the Moray Firth. The eye, from the top of this mountain, can reach almost as far as the North-West Highlands. Below, and to the west, lies Strath-Vaich in the Inchbae Forest. At the head of this strath lies a smaller strath through which the Rannoch Burn flows to join the Strath-Vaich, and these together join the Black-Water. The Rannoch Burn cuts through a deep deposit of red sandstones and shales, covered in its upper reaches by a vast accumulation of glacial drift.

Stratigraphical Position.

Walking up by the Rannoch Burn one may observe in the lie of the beds in the channel of the river, and in the cliffs forming the sides of the gorge, that the dip of those beds turns round from W. of N. to W. as we follow the course of the river. The angle of dip ranges from 15° to 25° towards a mass of gneiss rising to 1857 feet, known as *Meall nam Mullach*, which runs into this sandstone area as a promontory from the higher gneiss platform of Ardross. The deposit of sandstone sweeps round the base of this promontory into the bifurcating glens, Straith-Vaich and Strath-Rannoch. The area of the deposit is thus seen to be separated by the Wyvis range from the larger mass of the formation to the east of that range. A glance at the Ordnance sheet of the district will show that this area is separated from the larger tract of Old Red by the contour line of the watershed of the County. The beds are first met with in the Rannoch Burn close by the keeper's house at the height above sea of 1100 feet, and may be traced up stream to the contour line of 1250 feet.

Lithological Character.

At the keeper's house just referred to, the deposit may be seen, not absolutely resting on the underlying gneiss, either conformably nor unconformably, but, as it were, passing by fusion into the substance of the gneiss. Indeed at this spot, the river has broken for itself a passage by sweeping out masses which were separated from the parent mass by strike joints. The opposing faces of the passage tell a tale of violent disruption.

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The striæ on the slickenside faces on the right hand are inclined at an angle of 20° to the S.S.W., while those exactly opposite and across the stream are precisely at right angles to these. This indicates a torsion of no ordinary kind. That this torsion was accompanied by great heat is evident from the skin of adamant which has been formed on these slickensides, forming a hardness of such intensity indeed, that a steel hammer rings on the rock as if it were an anvil. Further up the stream the beds are formed of layers of a loose dark chocolate coloured shale, alternating with bands about 18 inches thick of a hard dark red sandstone. I was informed by men who worked this hard sandstone, that it dresses well and is admirably adapted for the making of lintels for doors and windows, and for the piers of bridges. These men, by the way, expressed to me their astonishment to find sandstone in a region of prevailing "granite," as they termed the gneiss. The lower and shaly beds up stream are spotted and interleaved with layers of a green argillaceous and calcareous shale of a similar consistency with the red shale.

Source of the Formation.

The vast masses of porphyritic gneiss scattered over this district, and down the valley of the Black-Water, and even over the ridge of the lower ranges of Wyvis to the south-east, right into Morayshire, originate in a broad belt of this gneiss which runs N.W. right into the centre of Ross-shire, from the foot of the N. slope of Wyvis to Carn-Cuinneag, 2700 feet in the heights of Ardross.

While the Wyvis range seems to have formed the eastern boundary of this Mid-Ross Old Red formation, an even higher range of hills must have existed to the north-west to have produced its north-western boundary. The process of degradation even in glacial times sent torrents of boulders off from that ancient chain of hills of porphyritic gneiss. In Ardross and in the neighbourhood of those hills the quantity of arkose, as well as the weathered look of the gneiss, bear further evidence to the rapid grinding down of what must have been higher mountains to the west than are now there. Into the basin hemmed in by those ranges the sand formed by weathering would have been swept. The deeply red colour of the deposit points also to the decomposed mica and felspar as those which supplied the ferric oxide. That this deposit of Old Red should be associated with the peculiar pink gneiss of Ross with its equally peculiar readiness to weather away, is at anyrate suggestive of a necessary connection of cause and effect between them. At anyrate, the idea may be taken for what it is worth.

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General Conclusion.

The existence of a deposit of Old Red above the 1000 feet contour line—if it be not really a minor basin determined by the conditions already indicated—must be looked on as an outlier of the general formation of Old Red Sandstone of the Devonian period. Its lithological character being identical with the Old Red of Lake Orcadie, suggests a community of origin and agencies. If that were so, it follows that the conditions which would have obtained here would hold equally good for the formation of Lake Caledonia, and hence for the whole of Scotland. In other words the Old Red formation, instead of being found in isolated areas over the country, would have covered it all over.

The stratigraphical character as well as the geographical position of the deposit points to its having been merely local.

I regret I was not able to make further observations on this Old Red outlier or minor basin as may be determined, owing to the difficulty I had of getting easily at the ground.

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PLANT REMAINS IN BASALT

FROM BO'NESS COALFIELD.

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XXIII.—*The Occurrence of Plant Remains in Olivine Basalt in the Bo'ness Coalfield.* By HENRY M. CADELL of Grange, B.Sc., F.R.S.E. [With Plate.]

(Read 19 February 1891.)

IN a paper which I read before the Edinburgh Geological Society on 26th January 1880, and which appears in the Transactions, vol. iii. pp. 304-325, a general stratigraphical account is given of the extensive series of interbedded volcanic rocks of the Bo'ness Coalfield in Linlithgowshire.

During the eleven years that have elapsed since that date some new facts of considerable geological interest have been elicited in the course of mining and quarrying operations in the district. Among these the most remarkable is perhaps the discovery of undoubted fragments of plants in some of the sheets of basalt interstratified with the carboniferous beds. In my former paper I referred to the occurrence of coniferous wood in some of the ash beds and neck tuffs that belong to the old volcanos of the carboniferous limestone series of Linlithgowshire, but such plant remains, although interesting, are not particularly remarkable or surprising in their mode of occurrence, as similar remains have been found elsewhere, and their origin is not at all difficult of explanation.

The plant remains I shall now briefly describe were found under much more unusual circumstances, and I may safely say that very few, if any, similar cases have been discovered in this country at least, in which the matrix surrounding the fossil consists of a crystalline massive volcanic rock.

During the summer of 1890 I had occasion, while carrying out some improvements at Cowdenhill, in the village of Grangepans, to remove part of a knoll of trap that forms a low cliff on the south side of the public road. The trap in question is the bed that lies in this part of the Bo'ness coalfield, about 30 feet above the seam known as the Red Coal. It dips westward from its outcrop at Cowdenhill, and has been pierced in No. 3 Pit of Grange Colliery about 80 yards further west, where it has a thickness of about 27 feet. That the rock is contemporaneous and not intrusive is clearly proved from the fact that (1) it has never been found to cut across the strata in the many sections where it has been laid bare; (2) the beds below are slightly indurated at places, while those above are unaltered; (3) the upper surface is highly amygdaloidal and usually somewhat decomposed.

Where the excavation was made there is no means of ascer-

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taining the distance from the top or bottom of the trap, but the rock is here quite solid and free from amygdules, and less decomposed than it usually is near the edges, so that the specimen to which I shall now refer was probably taken from near the centre of the old lava bed.

When first it was brought to light I took it for some species of mineral concretion, but a little examination soon proved that this could not be the case, as it not only looked remarkably like a lycopod stem, but was surrounded by a thin film of what appeared to be black carbonaceous matter. My friend Mr R. Kidston, F.R.S.E., F.G.S., who kindly examined it and took the photograph which is reproduced in the accompanying plate, reports as follows:—

"The specimen, which is preserved in greenstone (basalt), is 12 inches long. The upper extremity is about $1\frac{1}{10}$ inch in diameter, and owing to a fracture in the stone which contains the fossil, the upper 3 inches are broken off and lift out of the matrix. In section the stem at this part is slightly compressed on one side. The lower extremity measures 2 inches in its greatest diameter, but it is also slightly compressed. About 4 inches from the base a branch has been given off on the left side of about equal size to the stem preserved, but only its truncated base is left to indicate its position. The fossil lies on the angle ridge of a rudely four-sided block, whose shape is determined by the natural jointing of the basalt, and, like the exposed surfaces of the stone, is stained an ochreous brown colour. With the exception of this very thin coating of iron oxide, and perhaps a little carbonaceous matter mixed with it, the original plant in its upper part is entirely replaced by crystalline calcite, as shown at the fracture in the specimen to which reference has already been made.

"The broken base (which only in part shows a fresh surface) appears to consist of lime and matrix intermingled, but this may not be more than a coating at the broken end.

"There cannot remain the slightest doubt that the fossil is part of a *Lycopod* stem. Its outer surface might be described as an imperfectly-preserved specimen of *Knorria*, which, however, may have originated from a *Lepidodendron* or a *Lepidophloios*.

"The great interest of the specimen centres in the matrix in which it is preserved. The occurrence of a plant preserved in basalt is perhaps unique. The fossil was probably first reduced to a condition of 'charcoal' by the heat of the lava—a condition in which specimens are frequently found in volcanic ash,—and subsequently the carbon has been removed and the cavity filled up by infiltrated lime."

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I had some of the most carbonaceous-looking parts sliced for the microscope, but a close examination failed to show any traces of vegetable structure.

A microscopic examination of the rock, which Mr J. G. Goodchild, F.G.S., has been kind enough to make, shows it to present the character of a medium grained, hemicrystalline aggregation of (1) lath shaped crystals of plagioclase, apparently labradorite, forming quite three-fifths of the mass; (2) a small quantity of a mineral too much decomposed to be recognisable, but which may have been one of the pyroxenes; (3) large grains of serpentinised olivine of characteristic form and optical properties; (4) magnetite in small grains and crystals, evidently representing the oldest crystallization; (5) more or less interstitial matter, which remains dark through a complete rotation under crossed nicols, and which must, therefore, represent undifferentiated matter that originally existed as glass. The presence of olivine, which is even more abundant than that in the olivine basalt of the Lion's Haunch (Arthur's Seat), along with abundant plagioclase felspar and a ground-mass, shows the rock to be an olivine basalt. Although hard, it is considerably decomposed, but the accompanying drawing made for me by my

friend, Mr F. Grant Ogilvie, B.Sc., F.R.S.E., of a magnified section is quite sufficient to show its typical crystalline character.

In conclusion, it is interesting to reflect that had such a discovery been made three-quarters of a century ago, when the Huttonian and Wernerian controversy was at its height, it would doubtless have been triumphantly adduced as a proof of the correctness of the Neptunists' view that greenstone and trap are rocks of aqueous sedimentary origin, in which organic remains might reasonably be expected to occur.

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XXIV.—*On the more notable Scottish Earthquakes which have occurred during the present century.* By RALPH RICHARDSON, F.R.S.E., *Vice-President.* [*With Map.*]

(Read 19th March 1891.)

INTRODUCTION.

SCOTLAND has by no means an immunity from earthquakes. On the contrary, as the following paper will show, several earthquakes of considerable energy and affecting a wide area, have periodically occurred. In addition to these, there have been many hundreds of shocks, recorded and unrecorded, in various parts of the country. Mr Robert Mallet in his fourth Report to the British Association on earthquake phenomena, published in 1859, tabulates (p. 5) 234 "Earthquakes of the British Islands and Northern Isles," and points out that, of these, 56 occurred in Winter, 42 in Spring, 52 in Summer, and 67 in Autumn. The relative number for the four seasons was, Winter 1·03, Spring 0·76, Summer 0·96, Autumn 1·24; and during the two months of Perrey's "critical epochs," the number was as follows:—Winter solstice 1·28, Spring equinox 0·96, Summer solstice 0·53, Autumnal equinox 1·13.

Then, as to the horizontal direction of British earthquakes, Mallet remarks that Perrey computed a mean horizontal direction of S. 39° 5′ W. to N. 39° 5′ E., which is about the line of fracture of Loch Ness and the Great Glen.

Our late President, Mr Milne Home, discussed the earthquake phenomena of Scotland so long ago as 1842, in the "Edinburgh Philosophical Journal" (vols. xxxi.-xxxvi.), and the table of British earthquakes which he gives is interesting as exhibiting the time of year when the shocks occurred. It is as follows:—

	Scotland.	England.	Total for Great Britain.
January	14	11	
February	14	13	74. Winter months.
March	12	10	
April	9	10	
May	8	4	44. Spring months.
June	4	9	
July	5	5	
August	12	9	58. Summer months.
September	12	15	
October	14	11	
November	20	12	79. Autumn months.
December	15	7	
	139	116	

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During the present century, the most remarkable earthquakes which occurred in Scotland were those of the years 1816 and 1839. I shall therefore give some details of these, but I shall also, by way of comparison, refer to the well-observed earthquakes of 1801, 1880, 1889, and 1890, so that we may have before us at one time all the more notable Scottish earthquakes of the century. To facilitate comparison, I have constructed the accompanying map, which shows us at a glance the area affected by each of these earthquakes, as well as the great lines of fault and fracture in Scotland.

1st. *The Earthquake of 7th September* 1801.

Mr Thomas Lauder Dick[1] refers to this earthquake in the *Scots Magazine* of November 1816, in the course of an article on the important earthquakes of that year. In 1800 a slight shock had been felt at Inverness, which, as we shall find, is a locality noted for earthquakes. On 7th September 1801, a smart shock was experienced in the New Town, but not at all in the Old Town of Edinburgh, and in Leith and vicinity. A block of houses sank so considerably that the inhabitants had to leave it, whilst in Mid-Lothian a barn fell, crushing two women to death. Mr Lauder Dick considers that this earthquake had its centre in that well known seismic focus, Comrie, and says it was felt at Lochearnhead, Killin, Tyndrum, and Glenfinlas, extending southwards to Glasgow. It was also experienced at Perth, Callander, and on both sides of the Firth of Forth, at Grangemouth, Torryburn, Culross, Dunfermline, &c. The *Scots Magazine* of September 1801, says the barometer was high and had been rising for some time before. It adds that so extensive a shock had not been experienced in Scotland since the great earthquake at Lisbon on 1st November 1755, which was felt over a wide area in Europe, and which caused the waters of Lochs Lomond, Tay, and Ness, as well as of lakes and ponds throughout England, to rise and fall.

Turning to the *Edinburgh Magazine* for September 1801, we obtain greater details regarding the earthquake of 7th September. It continued two or three seconds at Edinburgh, and was preceded by a rumbling noise. Beds, tables, and chairs shook violently. The shock occurred at 6 A.M., and the morning was gloomy, warm, and calm. A previous slighter shock was noticed at 4 A.M. The earthquake was felt at the following additional localities,—viz., Paisley, Renfrew, Hamilton, Ayr, Stirling, Alloa, Linlithgow, and Amulree, Brig o' Turk, and Abernethy in Perthshire. At Comrie, two shocks occurred on 6th September (Sunday),

[1] Afterwards that well-known writer, Sir Thomas Dick Lauder, Bart.

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and alarmed a congregation in church. Next day a shock occurred at break of day, followed about 6 A.M. by one which is described by a local observer as "very great and alarming beyond expression. The earth, the great mountains around this village (Comrie), and the houses trembled like a balance for about the space of a minute. Slates fell from some houses, and many loose bodies tumbled down with great precipitation." This observer remarks that earthquakes have visited Comrie with more or less violence since August 1789, and generally happen at full moon or the change. The Aurora Borealis was very vivid for several nights before the earthquake of 7th September 1801.

From a table in the *Edinburgh Magazine* I observe that on 7th September 1801 the barometer at Edinburgh registered 29·7, whilst the thermometer was 48° before sunrise and 58° at noon. New moon occurred on 8th September, the day following the earthquake.

2*nd. The Earthquake of* 13*th August*, 1816.

Whilst Comrie was considered the centre of the earthquake of 1801, Inverness and its vicinity were believed to be the focus of that of 1816. According to the *Scots Magazine* for August 1816, the earthquake which occurred on 13th August of that year extended entirely across Scotland in a direction from W.N.W. to E.S.E. It was felt on the western coast of Ross-shire at Gareloch and Applecross and it strongly affected Coul, 18 miles to the west of Inverness. Inverness and its environs were rudely shaken a little before 11 p.m. Many persons (writes a local observer) fled from Inverness to the fields, and remained there for the greater part of the night. Chimney-tops were thrown down or damaged. A hotel was rent from top to bottom, whilst a spire was so seriously damaged that part required to be taken down. The day on which the earthquake occurred had been in Inverness beautiful and serene, and the weather remained unchanged. The barometer did not fall. I observe that at Edinburgh on 13th August 1816 the barometer was 30·05. New moon occurred on 23rd August.

From the *Inverness Journal* of the period we learn that the concussion on 13th August lasted about 20 seconds, and in many houses the bells rang for nearly a minute. The spire attached to the jail was found to be, at a distance of several feet from the top, completely rent and twisted several inches round in a direction from E. towards N.W. The earthquake was felt at Dingwall, Forres, and Pitmain, but it was more violent towards the north and west than towards the south and east.

At Montrose, however, the earthquake shortly before 11 p.m. seriously alarmed many families, and awoke them from sleep.

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Chairs and tables were put in motion, and next morning many doors were found difficult to open. One gentleman observed his bookcase move from the wall and fall back again upon it. The shock was felt in the vicinity of Montrose as far as Johnshaven. Two excisemen there were on the watch for smugglers, and were lying on the ground when the shock occurred, whereupon one of them leaped up and called to his companion: "There they are, for I feel the ground shaking under their horses' feet."

At Aberdeen also, about 11 p.m. the shock was distinctly felt for about 6 seconds. The undulation seemed to come from S.S.E., moved the heaviest articles of furniture, and set bells ringing. At Relugas, Morayshire, the seismic sound resembled that "of a great many pieces of heavy artillery driven furiously over a vaulted pavement," whilst everything was "heaved up and down." The barometer there was unaffected, and the thermometer marked 54°. At Logie, Lochindorb, Forres, Auldearn, Moy, and Grange the same alarming phenomena were observed; whilst at Dornoch, north of Inverness, the arches of the mound across the little ferry fell on account of the earthquake. At Peterhead, Fraserburgh, Dunkeld, and Perth the earthquake was also experienced for several seconds.

As already stated, Sir Thomas Dick Lauder, a well-known geological authority, described this and other Scottish earthquakes in the *Scots Magazine* for November 1816. He considers that the earthquake of 13th August 1816, "as it appears to have been infinitely more violent, so its influence seems to have been of wider extent than that of any of those which have hitherto agitated Great Britain." Whilst it was slightly felt at Glasgow, Coldstream, and Edinburgh, its range of active exertion lay between the Tay and the Pentland Firth. The total area affected must have been about 240 miles from north to south and about 160 miles from east to west. Strange to say, it did not agitate the waters of Loch Ness (as the Lisbon earthquake did), although the seismic centre was so near. The great bell of Inverness was distinctly heard to toll twice during the earthquake. Dick Lauder makes contradictory statements as to whether alluvial or rocky foundations were most affected by the earthquake, the truth apparently lying in his general observation "that every geognostic denomination of country seems to have submitted to the influence of the agitating power."

Nor was the Inverness district free from earthquakes after the great one of 1816, for, up to August 1817, five shocks were felt in Inverness, although (the *Scots Magazine* of September 1817 remarks) "the concussion was more violent in the districts of Urquhart, Aird, &c., to the westward of Inverness."

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3rd. The Earthquake of 23rd October 1839.

Mr Milne Home gives full particulars of this extensive earthquake in the "Edinburgh New Philosophical Journal" (vols. xxxii. *et seq.*) published in 1842-44. The "apparent focus of violence," according to him, was Comrie, a place where earthquakes have occurred so frequently that, for the two years following 3rd October 1839, 247 shocks are recorded in it,—171 during the six winter months from October to March inclusive, and 76 during the six summer months. Taking Comrie as a centre, and remarking that the earthquake of 23rd October 1839 was "the severest, unquestionably, of any which, within the memory of the oldest inhabitants, had been felt there," Mr Milne Home proceeds to note the localities affected and give the reports of observers. He first gives the accounts from Strathearn, the valley in which Comrie is situated, with reports from Lawers, Monzie, Crieff, and other places. The shock was felt about quarter-past ten at night without any previous warning. At Lawers "a loud and terrific explosion" was heard. A "tremulous motion passing along to the east was imparted to every object." The barometer had fallen an inch since 12 o'clock noon, and now stood at 29·8. Half-an-hour afterwards another loud explosion occurred, with the tremulous motion repeated, but the barometer was unaffected. The thermometer stood the whole night at 52°. During the night about 20 explosions occurred without any tremulous motion. Rain had fallen in the district incessantly for two whole days and nights, and Mr Milne Home remarks that especially during August, September, and October 1839, an unusual quantity of rain fell. The inhabitants of Comrie associate very wet weather with earthquake shocks.

Westwards from Comrie, this earthquake of 1839 was felt at Dunira, Ardvoirlich, Glenbuckie, Callander, Luss and Cameron House on Loch Lomond, 3 miles S.-W. of Glasgow; and Finnart on Loch Long. To the north-west of Comrie it was felt at Clenary, 4 miles from Inverary, Dunolly, near Oban, Ardgour, in Inverness-shire, and at Appin. To the north of Comrie it was felt at Dull in Aberfeldy, Kingussie on Speyside, Inverness, Fort Augustus, Glen Urquhart, Strathglass, Beauly, Dingwall, and Forres. To the north-east of Comrie the earthquake was felt at Fraserburgh, 110 miles from Comrie; Strichen near Fraserburgh, Banchory, Aberdeenshire; Finzean, Aberdeen, Blairgowrie, Spittal of Glenshee, and Kirkmichael in Strathardle. Then to the east of Comrie, it was felt at Shanwell near Kinross, Kinross town, Perth, and St Andrews. To the south-east of Comrie it was felt at Balgone near North Berwick, Musselburgh,

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Prestonpans, Newbyth, Trinity, Edinburgh, Dunning, Muckhart in Ochils, Dollar, Tillicoultry, Alva, and Alloa. To the south of Comrie it was felt at Airth and Throsk near Stirling, Stirling, Thornhill, Blairdrummond, Bucklyvie, Selkirk, Kelso, Coldstream, Closeburn, Dumfriesshire; and Netherby Hall, 10 miles north of Carlisle.

From this recital of localities, it is evident that the area affected by this earthquake was most extensive. "The shock," says Mr Milne Home, "was felt throughout two-thirds of Scotland." Again, the rapidity of the passage of the earthquake is most extraordinary, all this vast region being apparently struck simultaneously, the blow, however, being felt most severely at Comrie. One observer at Comrie reported "I felt the shock strike the ground perpendicularly under my feet three times, like the stroke of a ponderous hammer; and as far as I can guess, lifted the ground six or eight inches." "In a great number of the reports, it is remarked that the undulations were most striking in carse or alluvial grounds, though the accompanying *noise* was not so great there as on rocky ground." Comrie, the centre of the earthquake, adjoins an important line of fault stretching from the Kincardine coast in a S.W. direction past Comrie to Loch Lomond.

Miss Milne Home has kindly shown me some correspondence[1] which, in March 1840, passed between her father, Dr Daubeny (the author of the well-known work on "Volcanoes") and Charles Darwin, regarding the earthquake phenomena of Scotland. In the course of that correspondence Darwin makes the following suggestion:—"On the hypothesis of the crust of the earth resting on fluid matter, would the influence of the moon (as indexed by the tides) affect the periods of the shocks, when the force which causes them is just balanced by the resistance of the solid crust?"

In this correspondence, Mr Milne Home describes certain curious phenomena observed not long after the great earthquake of 1839. He says that on 16th November 1839 "jets of smoke or steam were observed to issue from the side of a hill in Glenalmond, 8 miles north-east from the focus of the Comrie shocks, and stones were by these jets raised out of their beds." Again, on 15th January 1840, about 200 yards from the place where the jets of smoke or steam appeared, a flame was seen. On making enquiry, Mr Milne Home learnt that "such a flame has been seen occasionally for the last twenty or thirty years arising from the same spot." . . . "It shows itself chiefly in the winter time. Its colour is blue or purple. The place from which it issues is

[1] Given in full in her interesting Life of our deceased President, published by Mr Douglas, Edinburgh, 1891.

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rocky and precipitous." Mr Milne Home consulted both Darwin and Daubeny as to the probable origin and nature of this flame. Darwin's reply has not been preserved. Daubeny thought it would "turn out to be a pseudo-volcanic phenomenon," and not necessarily connected with earthquakes. "Why," he asks, "should earthquakes be necessarily connected with volcanoes? Is it not more probable that those, for example, that are so frequent in the county of Sussex should be connected with some local cause of that kind, such, for example, as in the neighbouring county of Dorset has produced the landslip near Lyme accompanied, it is said, with shocks of the same description. . . . I assume, of course throughout, that the gas will turn out to be some form of carburetted hydrogen which, having become kindled by accident, goes on burning till extinguished. Should it turn out to be phosphuretted hydrogen, it would indeed be an addition to our knowledge."

4th. The Earthquake of 28th November 1880.

This earthquake is described by Mr Charles A. Stevenson in the *Proceedings of the Royal Society of Edinburgh* for 21st March 1881 (Vol. xi., p. 176), and seemed to have its centre near Phladda Lighthouse, to the east of Colonsay. Like the earthquake of 1839, it occurred after a wet period, the barometer ranging between 29 and 30. Like the 1839 earthquake also, its source or centre, Phladda, lay near a great fracture, namely, one which runs along the Great Glen in a south-westerly direction from Inverness. It was also a winter earthquake.

Mr Stevenson states that "the seismal area was about 19,000 square geographical miles, the shock having been felt as far north as the Butt of Lewis, as far south as Armagh in Ireland, as far east as Blair Atholl, and as far west as Barrahead, though how much farther it was propagated into the Atlantic it is impossible to say." The area influenced by this earthquake may be roughly said to be bounded by the towns of Inverness, Blair Athole, Callander, Motherwell, Ayr, Belfast, Armagh, Omagh, and Letterkenny; the circle being completed by the Outer Hebrides, as far north as the Butt of Lewis.

The earthquake was felt throughout this immense area almost simultaneously everywhere. For example, it was felt at Belfast in Ireland and at Ushenish, which is in the island of South Uist, at precisely the same moment—viz., 5.53 P.M., although these two places are 200 miles apart. Phladda (the supposed seismic centre) is about equi-distant from these two places.

Again, this earthquake, like that of 1839, raises the interesting point whether buildings erected on solid rock feel earthquake shocks more acutely than those built on other material. Mr

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Stevenson says that "the stations (mostly lighthouses) where the noise was heard were for the most part situated on hard, dense rocks, with little or no soil near them." Dr Johnston-Lavis of Naples, from his careful examination of the result of the disastrous Ischia earthquake of 1883,[1] came to the conclusion that houses built on rock suffer much more than those built on sand or tufa. In our Edinburgh earthquake of 1889, however, the shock was not felt by the soldiers living in the Castle, which is built on solid rock.

Once more, this earthquake of 1880 seems to corroborate Mr Milne Holme's view (Vol. xxxi. p. 283[2]) that earthquakes are most frequently felt in localities where the more ancient rocks occur: for Mr Stevenson states "that of twenty-two lighthouse observers between Cape Wrath and the Mull of Galloway, who were situated on the older formations (Laurentian, Cambrian, and Metamorphosed Lower Silurian), eleven felt the shock; whilst of thirteen observers on newer rocks, it made itself known only to two of them." This earthquake therefore, in his opinion, was more generally felt on the older rocks of Scotland.

5th. The Earthquake of 18th January 1889.

Full details regarding this earthquake will be found in the paper which I read before the Edinburgh Geological Society on 21st February 1889, and which was published in the *Scottish Geographical Magazine* for March 1889, with an excellent map by Messrs Bartholomew, illustrating the times and apparent directions of the shocks. There were two shocks, but the second, shortly before 7 A.M., was the principal one. This shock was experienced throughout an area extending as far north as Burntisland, as far east as Dalkeith, as far south as Peebles, and as far west as Linlithgow. The city of Edinburgh felt it in numerous localities, but, as in the earthquake which occurred in 1801, the Old Town and the Castle do not seem to have been affected. Both during the earthquakes of 1801 and 1889, in this district, the barometer and thermometer were high. The earthquake of 1889 was a winter one, but did not occur after wet weather. The meteorological conditions, however, which produce accumulations of gas in mines, were present both during this earthquake and one which occurred throughout a great part of Scotland in 1888; and the disastrous colliery explosion occurred at Hyde, Cheshire, about two hours after the Edinburgh earthquake of 1889. Eclipses of the moon preceded the earthquakes of 1888 and 1889. Full moon occurred on

[1] Monograph of the Earthquakes of Ischia, especially those of 1881 and 1883, published at London and Naples, 1885. This masterly work is finely illustrated by photographs, &c.

[2] *Op. cit. supra.*

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17th January 1889, and the earthquake was next day. Full moon occurred on 22nd October 1839, and the earthquake was also next day. Full moon cannot, however, be connected with the earthquakes of 1888 or 1890.

6*th. The Earthquake of* 15*th November* 1890.

My information regarding this earthquake is obtained from articles and letters which appeared in the *Scotsman* and other newspapers immediately after its occurrence. This earthquake[1] had a wide area, extending as far north as Dunbeath on the Caithness coast, as far east as Fraserburgh and Aberdeen, as far south as Huntingtower, near Perth, and as far west as Drumnadrochit and Strathglass. This area, wide as it is, is mostly included in the much more extensive area of the earthquake of 23rd October 1839, to which I have already drawn attention. The time of the first shock, on 15th November 1890, appears to have been a little before 6 P.M., and there was a second shock at 6.20 P.M. A clock was stopped at Inverness at 5.50 P.M., and the shock was distinctly felt at Huntingtower, near Perth, 80 miles distant, at 5.51. Like the other earthquakes noticed, this was a winter one, but it did not follow much rain. The barometer at Drumnadrochit was 30·1 and rising. Observers there thought the wave proceeded in a direction between E. and S.E. However, at Inverness an observer thought it passed S.W., and, as usual, observers differ widely in this matter. Spring tide, new moon, and a high barometer[2] all occurred at Inverness during or shortly preceding this earthquake, which was on Saturday, 15th November 1890, and was generally admitted to be "the greatest that had occurred in the district for many years." Next day (Sunday) a distinct shock was felt at Drumnadrochit at 8.29 P.M., and again the movement seemed to be in an easterly direction. The same morning (Sunday, 16th November), at half-past three o'clock, a sharp shock was experienced at Inverness. "The shock," said next day's *Scotsman*, "was of such severity as to waken almost the soundest sleeper, and for a time there was considerable excitement and alarm. In an instant, almost every house was lit up, and in several cases the people rushed to the street, under the belief that their houses would topple over. This shock is the eighth which has been distinctly felt along the valley of the Ness since

[1] An elaborate account of the Inverness earthquakes of 15th November to 14th December 1890, by Mr Charles Davison, appears, with a map, in the *Quarterly Journal*, Geological Society of London, vol. xlvii. p. 618 (November 1891). His map does not exhibit the full seismic area.

[2] Prof. Milne of Japan, in his able treatise on earthquakes in the "International Scientific Series" (1886) discusses these seismic influences.

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the 15th November, and in severity was only equalled by the first shock on the evening of that day." These frequent shocks about this period in the Ness valley do not seem to have been felt beyond it, and in this respect differ greatly from the shock on the evening of Saturday, 15th November, a little before six o'clock, which affected the wide area already noticed. With reference to a former remark as to the greater frequency of earthquakes on the older than the newer rocks, their occurrence so often in 1890 in the Ness valley is remarkable, as from Loch Ness to the sea the rocks of the Ness valley consist of Post-tertiary deposits. Dingwall also, where a "very severe shock of earthquake was felt a little before six o'clock" on the evening of Saturday, 15th November, is situated on deposits of Post-tertiary age. Inverness and Dingwall were affected by the four earthquakes of 1816, 1839, 1880, and 1890.

Conclusion.

In order to gather together, for comparison, some of the leading details regarding these the more notable Scottish earthquakes of the present century, I have prepared the following tables which, with the accompanying map, will give information never yet published in one paper.

A. *Comparative Details of each Earthquake.*

Earthquake.	Hour.	Approximate Area affected.		Supposed Centre.	Barometer at Centre.	Thermometer at Centre.	Phase of Moon.	Supposed Direction of Earthwave.
		Length. Miles.	Breadth. Miles.					
Sept. 1801,	6 A.M.	90	70	Comrie.	29·7[1]	48°[1]	Day before New Moon.	From S.W.
Aug. 1816,	11 P.M.	200	142	Inverness.	29·8[2]	64°[2]	Approaching last Quarter.	From W.N.W.
Oct. 1839,	10 P.M.	217	188	Comrie.	29·8	52°	Day after Full Moon.	From W.
Nov. 1880,	6 P.M.	280	230	Phladda.	29·9	50°	Approaching New Moon.	From W.S.W.
Jan. 1889,	7 A.M.	85	85	Edinburgh.	29·9	53°	Day after Full Moon.	Uncertain.
Nov. 1890,	6 P.M.	130	130	Inverness.	29·9	51°	3 days after New Moon.	Uncertain.

[1] No records then kept at Comrie. The above readings are those taken in the vicinity of Edinburgh, where the earthquake was felt.

[2] No records then kept at Inverness. The above readings are those taken at Gordon Castle, Elginshire, where the earthquake was felt.

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B. *Alphabetical List of Localities affected by more than one notable Earthquake.*

Locality.	Earthquakes of					
	1801	1816	1839	1880	1889	1890
Aberdeen,		×	×			×
Alloa,	×		×			
Amulree, Perthshire,	×		×			
Ayr,	×			×		
Callander,	×		×	×		
Coldstream,		×	×			
Comrie,	×†		×†			
Dingwall,		×	×	×		×
Dunkeld,	×	×				
Edinburgh,	×	×	×		×†	
Forres,		×	×			×
Fraserburgh,		×	×			
Glasgow,	×	×				
Inverary,			×	×		
Inverness,		×†	×	×		×†
Linlithgow,	×				×	
Nairn,			×			×
Perth,	×	×	×			
Stirling,	×		×			

† Supposed centre of the Earthquake.

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XXV.—*Homacanthus Borealis Traq. A New Selachian from the Lower Old Red of Caithness.* By W. Tait Kinnear. With Plate and description by Dr R. H. Traquair, F.R.S.

(Read 7th May 1891.)

The specimens which form the material on which this paper is based were found by me in the flag fences on the farm of Lybster in the parish of Reay. Owing to various difficulties in growing hedges, such as exposure to severe storms from the Atlantic Ocean and a very cold subsoil, farmers and estate officials have recourse to the flagstones which are almost invariably found immediately beneath the surface, especially in the north-western portion of the county. If it happens that a fossiliferous bed is opened out, then careful searching will often reveal some of the fish-remains for which the Lower Old Red is famous. The commonest beds which yield fossil-fishes to any great extent are the Osteolepis beds, which are of a light chocolate colour, weathering to a bluish white. These beds, however, are too soft for fencing purposes. Consequently one need never expect to find in the fences fishes characteristic of these beds. Thus, it comes about that the scales, teeth, plates, and head-bones that are to be found, are characteristic of fishes that occur in the beds where fossil-remains are found only to a somewhat scanty extent. They are representative, therefore, of rarer fishes, and are worthy of more than usual attention. Numerous spines occur in the Lower Old Red as developed in the neighbourhood of Thurso. The great majority of these, however, are at once seen to be Acanthodian in nature and characteristic of the genera *Mesacanthus* and *Diplacanthus*. It was accordingly a matter of great surprise to me when one evening I noticed in one of the flags bordering the public highway, skirting the farm of Lybster, a very small piece of a spine, ribbed and furrowed in a manner very similar to the carboniferous species *Tristychius arcuatus*. On further search all over the farm, I was able to collect a few additional specimens. The task, however, was not an easy one. The flag was as hard as adamant, the spines were excessively fragile. Nearly all the specimens had to be bound to the matrix with gummed paper, otherwise they detached themselves from it at the last moment, and were either broken or lost. Luckily, the best specimen (which is now the type species) detached itself from the matrix when the work of cutting it out by means of a sharp chisel had hardly been finished, and it therefore became possible to view both sides of the spine. Not

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long afterwards, I mentioned to Dr Traquair that I had found some spines which bore a strong resemblance to *Tristychius*. I handed over to him the spine already mentioned, which he identified as belonging to the genus *Homacanthus*. The species, however, was new, and he has been kind enough to write a description of it, which is appended to this paper. I saw nothing of the nature of shagreen nor any teeth accompanying the spines.

The flag in which this interesting Selachian was found must have come from a quarry in the immediate neighbourhood. It is naturally of a blue colour, but weathers to a creamy white. The horizon of the bed is within a few hundred feet of the top of the Lower Old Red as developed in the north-western portion of Caithness. This does not take into account the John o' Groats beds which are reckoned to be the top of the Lower Old Red as found in Caithness and the Orkneys. The discovery of a spine belonging to the well-known Carboniferous genus *Gyracanthus* in the Lower Devonian of Canada[1] was a great incentive to searching the beds in this part of the county for Selachian remains, which have representatives already in the higher rocks. The great assemblage of genera and species of sharks in the Lower Carboniferous must have had ancestors in Old Red Sandstone times, but these have hitherto been conspicuous for their absence. It is to be hoped that subsequent researches will throw more light on this subject.

[1] R. H. Traquair, *Geol. Mag.* (3) vol. vii., 1890, p. 21.

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Description of a Selachian Spine found by Mr W. Tait Kinnear in the Old Red Sandstone of Caithness. By R. H. TRAQUAIR, M.D., F.R.S.

THE spine submitted to me by Mr Kinnear measures $1\frac{5}{8}$ inch in length, but the base or inserted portion is not present; its greatest antero-posterior depth, where it is broken off, is $\frac{3}{16}$ inch. It is elegantly curved backwards and sharply pointed at the apex; laterally, it is much compressed. Externally, the spine is marked by clear-cut longitudinal smooth rounded ridges and sulci, which are, however, only distinctly shown on the left side, which has been weathered. Here, towards the base, six ridges are seen, one of which is median and extends to the apex; the others disappear in succession as the apex is approached. On the posterior aspect of the spine a narrow area is present, which is, however, thrown a little over to the right side, I think by distortion resulting from pressure, and therefore not due to original conformation. Each margin of the area is set with a row of very small closely-set recurved and adpressed denticles, there being four in the space of $\frac{1}{8}$th inch. The two rows of denticles are traceable from the apex downwards for a distance of $\frac{7}{8}$th inch.

The spine agrees in its characters exactly with the genus *Homacanthus* as defined in the works of Agassiz,[1] M'Coy,[2] and Smith Woodward.[3] Only three reliable species of the genus are as yet known—namely *H. arcuatus* Ag. from the Old Red of Russia, and two species from the carboniferous limestone of Ireland, *H. microdus* and *macrodus* of M'Coy. The spine from Caithness is undoubtedly distinct specifically from all of these, though it most resembles in shape the Old Red *H. arcuatus* Ag. from which, however, judging from the figures of Agassiz and Eichwald,[4] it differs by the posterior denticles being smaller, more close together, and more adpressed.

My thanks are due to Mr Kinnear for the opportunity of examining and describing this interesting addition to the fish-fauna of the Scottish Old Red Sandstone.

[1] "Poiss. Foss. vieux Grès rouge" (1845) p. 113.
[2] "Pal. Foss." p. 632 (1855).
[3] "Cat. Foss. Fishes, British Museum," pt. ii. (1891) p. 105.
[4] "Lethæa Rossica," vol. i. pl. 55, fig. 9 (under the name of *Homacanthus gracilis*).

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Description of the Figures.

Fig. 1. *Homacanthus borealis* Traq. seen from the left side and magnified one-half.

Fig. 2. Portion of the same spine one-third from the apex, magnified four diameters.

Fig. 3. Posterior aspect of the spine at the same place to show the two rows of denticles.

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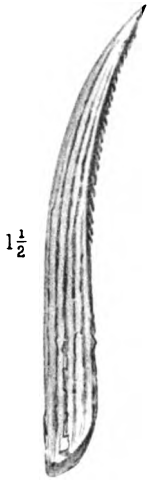

Fig. 1.

Fig. 2.

Fig. 3.

R. H. Traquair, M.D. del. M°Farlane & Erskine, Lith^rs Edin^r

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FIFTY-EIGHTH ANNIVERSARY MEETING.

SESSION 1891-92.

XXVI.—*Supposed Causes of the Glacial Period.* Address by Prof. JAMES GEIKIE, D.C.L., LL.D., F.R.S., *President of the Society.*

(18th November, 1891).

IN addressing you for the first time from this chair, I shall make no apology for directing your attention to a question which has already been discussed so frequently and at such length, that one might suppose hardly anything remains to be said upon the subject. The question I refer to is the cause or causes of the climate of Pleistocene times. Notwithstanding all that has been written about this question, however, the last word has not yet been said; and I do not doubt that the particular origin of glacial and interglacial conditions will continue to be canvassed and discussed long after the present generation of geologists has passed away. The question is beyond measure a hard one. We are called upon to deal with so wide a range of facts and phenomena—each of which must be satisfactorily accounted for—that it is difficult indeed to keep them all in view, and to assign to each its relative importance. Now, I may at once premise that I am not about to advance any novel speculation or hypothesis. My object is rather to examine certain views which, after having been abandoned years ago as untenable, have again been put forward to explain and account for the phenomena of the Glacial period. Before proceeding to my criticism, however, it will be needful to state first, as shortly as I can, the general conclusions which have been arrived at with regard to the climatic conditions of Pleistocene and Postglacial times. For it is obviously necessary to have an adequate conception of those conditions before attempting to estimate the value of any theory of their origin. The main conclusions, then, are as follows:—

1. It has been shown that during the Pleistocene period cold conditions of climate supervened oftener than once, and that in

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Postglacial times also the climate of our present temperate regions was, for a while at least, colder than now. It is quite unnecessary that I should present you with even the slightest sketch of the aspect presented by the glaciated tracts of our hemisphere at the climax of the Ice Age. The geographical distribution and extent of the old snow-fields, glaciers, and ice-sheets is matter now of common knowledge. It is necessary, however, that we should clearly understand the nature of the conditions which obtained at the climax of glacial cold—at that stage, namely, when the Alpine glaciers reached their greatest development, and when so much of Europe was cased in snow and ice. This we shall best do by comparing the present with the past. Now in our day the limits of perennial snow are attained at heights that necessarily vary with the latitude. This is shown as follows:—

Region.	N. Lat.	Height of Snow-Line.
Iceland,	65°	3070 feet.
Norway,	61°	5180-5570 „
N. Urals,	59°30	4790 „
Alps,	46°	8884 or 9000 „
Caucasus,	43°	10,600-11,000 „
Apennines,	42°30	9520 „
Etna,	37°30	9530 „
Sierra Nevada,	37°	11,187 „

Thus in traversing Europe from north to south the snow-line may be said to rise from 3000 feet to 11,000 feet in round numbers. It is possible from such data to draw across the map a series of isochional lines, or lines of equal perennial snow, and this has been done by my friend, Professor Penck of Vienna.[1] It will be understood that each isochional line traverses those regions above which the line of névé is estimated to occur at the same height. Thus the isochional line of 1000 metres (3280 feet) runs from the north of Norway down to lat. 64° on the west coast, whence it must pass west to the south of Iceland. The line of 1500 metres (4920 ft) is traced from the north end of the Urals in a westerly direction. It then follows the backbone of the Scandinavian peninsula, passes over to Scotland, and thence strikes west along lat. 55°. For each of these lines good data are obtainable. The line of 2000 metres (6560 ft.) is, however, hypothetical. It is estimated to extend from the Ural mountains, about the lat. of 57° over the mountains of Middle Germany, and above the north of France. The line of 2500 metres (8200 ft.) passes from

[1] "Geographische Wirkungen der Eiszeit," *Verhandl. d. vierten deutschen Geographentages zu München*, 1884.

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the southern termination of the Urals, in lat. 51°, to the East Carpathians, thence along the north face of the Alps, thereafter, south-west across the Cevennes to the north-west end of the Pyrenees; and thence above the Cantabrian and the Portuguese Highlands to the coast in lat. 39° The line of 3000 metres (9840 ft.) is estimated to occur above the Caspian Sea, near lat. 44°, and extends west through the north end of the Caucasus to the Balkans. Thence it is traced north-west to the Alps, south-west to the Pyrenees, which range it follows to the west, and thereafter sweeps south above the coast at Cadiz. The line of 3500 metres (11,480 ft.) runs from the Caucasus south-west across Asia Minor to the Lebanon Mountains; thence it follows the direction of the Mediterranean, and traverses Morocco above the north face of the Atlas. Finally the line of 4000 metres (13,120 feet) is estimated to trend in the same general direction as the last-mentioned line, but of course further to the south. Although these isochional lines are to some extent conjectural, yet the data upon which they are based are sufficiently numerous and well-known to prevent any great error, and we may admit that the lines represent with tolerable accuracy the general position of the snow-line over our Continent. So greatly has our knowledge of the glaciation of Europe increased during recent years, that the height of the snow-line of the Glacial period has been determined by MM. Simony, Partsch, Penck, and Höfer. Their method is simple enough. They first ascertain the lowest parts of a glaciated region from which independent glaciers have flowed. This gives the maximum height of the old snow-line. Next they determine the lowest point reached by such glaciers. It is obvious that the snow-line would occur higher up than that, but at a lower level than the actual source of the glaciers; and thus the minimum height of the former snow-line is approximately ascertained. The lowest level from which independent glaciers formerly flowed, and the terminal point reached by the highest-lying glaciers having been duly ascertained, it is possible to determine with sufficient accuracy the mean height of the old snow-line. The required data are best obtained, as one might have expected, in the Pyrenees and amongst the mountains of Middle and Southern Europe. In those regions the snow-line would seem to have been some 3000 feet or so lower than now. From such data Professor Penck has constructed a map showing the isochional lines of the Glacial period. These lines are, I need hardly say, only approximations, but they are sufficiently near the truth to bring out the contrast between the Ice Age and the present. Thus the isochional of 1000 metres, which at present lies above Northern Scandinavia, was pushed south to the latitude of Southern France and North Italy; while

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the isochional of 2000 metres (now overlying the extreme north of France and North Germany) passed in glacial times over the northern part of the Mediterranean.[1]

Isochional lines are not isotherms. Their height and direction are determined not only by temperature, but by the amount and distribution of the snow-fall. Nevertheless, the position of the snow-line in Europe during the Ice Age enables us to form a rough estimate of the temperature. At present in Middle Europe the temperature falls 1° F. for every 300 feet of ascent. Hence if we take the average depression of the snow-line in Glacial times at 3000 feet, that would correspond approximately to a lowering of the temperature by 10°.[2] This may not appear to be much, but, as Penck points out, were the mean annual temperature to be lowered to that extent it would bring the climate of Northern Norway down to Southern Germany, and the climate of Sweden to Austria and Moravia, while that of the Alps would be met with over the basin of the Mediterranean.

Let it be noted further that this lowering of the temperature —this displacement of climatic zones, was experienced over the whole continent—extending on the one hand south into Africa and on the other east into Asia. But while the conditions in Northern and Central Europe were markedly glacial, further south only more or less isolated snow-capped mountains and local glaciers appeared—such, for example, as those of the Sierra Nevada, the Apennines, Corsica, the Atlas, the Lebanon, &c. In connection with these facts we may note also that the Azores were reached by floating ice; and I need only refer in a word to the evidence of cold wet conditions as furnished by the plant and animal remains of the Pleistocene tufas, alluvia, and peat of Southern Europe. Again in North Africa and Syria we find, in now dessicated regions, wide-spread fluviatile accumulations, which, in the opinion of a number of competent observers, are indicative of rainy conditions contemporaneous with the Glacial period of Europe.

When we compare the conditions of the Ice Age with those of the present we are struck with the fact that the former were only an exaggeration of the latter. The development of glacia-

[1] It is interesting to note that while in the Tatra (North Carpathians) the snow-line was depressed in glacial times to the extent of 2700 feet only, in the Alps it descended some 4000 feet or more below its present level. With the snow-line of that great chain at such an elevation it is obvious that only a few of the higher points of the Apennines could rise into the region of névé. This is the reason why moraines are met with in only the higher valleys of that range.

[2] Professor Brückner thinks the general lowering of temperature may not have exceeded 5½° to 7° F. *Verhandlungen der 73 Jahresversammlung der Schweitzerischen Naturforschenden Gesellschaft in Davos*, 1890.

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tion was in strict accordance with existing conditions. Thus in Pleistocene times North America was more extensively glaciated than Northern Europe, just as to-day Greenland shows more snow and ice than Scandinavia. No traces of glaciation have been observed as yet in Northern Asia or in Northern Alaska and to-day the only glaciers and ice-sheets that exist in northern regions are confined to the formerly glaciated areas. Again, in Pleistocene Europe glacial phenomena were more strongly developed in the west than in the east. Large glaciers, for example, existed in Central France, and a considerable ice-flow poured into the basin of the Douro. But in the same latitudes of Eastern Europe we meet with few or no traces of ice-action. Again, the Vosges appear to have been more severely glaciated than the mountains of Middle Germany; and so likewise the old glaciers of the Western Alps were on a much more extensive scale than those towards the east end of the chain. Similar contrasts may be noted at the present day. Thus we find glaciers in Norway, under lat. 60°, while in the Ural Mountains in the same latitude there are none. The glaciers of the Western Alps, again, are larger than those in the eastern part of the chain. The Caucasus, it is true, has considerable glaciers, but then the mountains are higher. Now turn for a moment to North America. The eastern area was covered by one immense ice-sheet, while in the mountainous regions of the west gigantic glaciers existed. In our own day we see a similar contrast. In the north-east lies Greenland well-nigh drowned in ice, while the north-west region on the other hand, although considerably higher and occurring in the same latitude, holds only local glaciers. We may further note that at the present day very dry regions, even when these are relatively lofty and in high latitudes, such as the uplands of Siberia, contain no glaciers. And the same was the case in the Glacial period. These facts are sufficient to show that the conditions of Glacial times bore an intimate relation to those that now obtain. Could the requisite increase of precipitation and lowering of temperature take place we cannot doubt that ice-sheets and glaciers would reappear in precisely the same regions where they were formerly so extensively developed. No change in the relative elevation of the land would be required—increased precipitation accompanied by a general lowering of the snow-line for 3000 or 3500 feet would suffice to reintroduce the Ice Age.

From the foregoing considerations we may conclude:—1. That the cold of the Glacial period was a general phenomenon, due to some widely-acting cause—a cause sufficient to influence contemporaneously the climate of Europe and North America; 2. that glaciation in our continent increased in intensity from east

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to west, and from south to north; 3. that where now we have the greatest rain-fall, in glacial times the greatest snow-fall took place, and the snow tended most to accumulate; 4. that in the extreme south of Europe, and in North Africa and West Asia, increased rain precipitation accompanied lowering of temperature, from which it may be inferred that precipitation in glacial times was greater generally than it is now.

2. Having considered the climatic conditions that obtained at the climax of the Glacial period, I have next to recapitulate what is known as to the climatic changes of Pleistocene times. It is generally admitted that the glacial conditions of which I have been speaking were repeated twice, some say three times, during the Pleistocene period; while others maintain that even a larger number of glacial episodes may have occurred. Two glacial epochs, at all events, have been recognised generally both in Europe and North America. These were separated by an interglacial stage of more genial conditions, the evidence for which is steadily increasing. No one now calls in question the existence of interglacial deposits, but, as their occurrence is rather a stumbling-block in the way of certain recently resuscitated hypotheses, some attempt has been made to minimise their importance—to explain them away, in fact. It has been suggested, for example, (and the suggestion is by no means new) that the deposits in question only show that there were local oscillations during the advance and retreat of the old ice-sheets and glaciers. This, however, is not the view of those who have observed and described interglacial beds—who know the nature of the organic remains which they have yielded, and the conditions under which the beds must have been accumulated. I need not refer to the interglacial deposits of our own country further than to remark that they certainly cannot be explained away in that summary fashion. The peat and freshwater beds that lie between the lower and upper tills in the neighbourhood of Edinburgh, for example, are of themselves sufficient to prove a marked and decided change of climate. No mere temporary retreat and re-advance of the ice-sheet will account for their occurrence. The lower till, as you know, is the bottom moraine of an ice-sheet which, in this region, flowed towards the east. When the geographical position of the deposits in question is considered it becomes clear that an easterly flow of ice in this neighbourhood proves beyond gainsaying that during the accumulation of the lower till all Scotland was drowned in ice. But when water once more flowed over the land-surface—when a temperate flora, composed of hazels and other plants, again appeared, it is obvious that the ice-sheet had already vanished from Central

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Scotland. This is not the case of a mere temporary recession of the ice-front. It is impossible to believe that a temperate, or even cold-temperate flora, could have flourished in Central Scotland at a period when thick glacier-ice mantled any portion of our lowlands. Again, in the upper till we read the evidence of a recurrence of extreme glacial conditions—when Central Scotland was once more overwhelmed by confluent ice-streams coming from the Highlands and the Southern Uplands. Similar evidence of recurrent glacial conditions, I need hardly remind you, has been detected in other parts of the country. We are justified, then, in maintaining that our interglacial beds point to distinct oscillations of climate—oscillations which imply a long lapse of time. Continental observers are equally convinced that the interglacial epoch of which so many interesting relics have been preserved over a wide region was marked at its climax by a temperate climate and endured for a long period. The interglacial beds of Northern and Central Europe form everywhere a marked horizon in the glacial series. They have been traced at intervals across the whole width of the continent from the low countries bordering on the North Sea to the heart of Central Russia. In this latter region they have been detected quite recently by M. Krischtafowitsch, according to whom their flora and fauna indicate a climate somewhat warmer or moister than the present. He is further convinced that the interglacial stage was of long duration, and concludes that in Russia as in Western Europe there were two distinct periods of extensive glaciation, separated by a protracted interglacial epoch. Again, it has been demonstrated by Heer, and more recently by Penck and others, that distinct interglacial stages characterised the Ice Age of the Alpine lands. And similar conclusions as to the Glacial period of Central France and the Pyrenees have been reached by M. Julien, M. Rames, and others.

I have spoken of one interglacial stage as having been proved for all the great glaciated areas of Europe. It is quite possible, however, that the interglacial deposits which have been described do not all belong to one and the same stage. For anything that we can tell there may have been several such stages in the Pleistocene history of North-western Europe. This possibility must not be lost sight of in view of what we now know of the glacial and interglacial stages of the Alpine lands. Professor Penck has shown, and his observations have been confirmed and extended by others, that the valleys of the Bavarian Alps have been occupied by glaciers at three successive periods—each being separated from the other by an epoch of fluviatile conditions, during which great rock-erosion was effected, and very thick river-deposits were accumulated. The

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same eminent observer informs me that he has detected a similar succession on the south side of the Alps, in the district of Lake Garda. He there finds evidence of three different and successive glaciations, with intervening stages marked by great valley-erosion and the deposition of massive sheets of fluviatile detritus.

The flora and fauna met with in the interglacial deposits of Northern and Central Europe indicate, as I have said, cold-temperate, temperate, and genial conditions. The interglacial lignites of North Italy show that the climate of the mountain-valleys in which they occur (Leffe, near Gandino) was during interglacial times as warm as that of the plains of Lombardy; and the interglacial deposits of Auvergne tell a similar tale. It is now, I believe, generally admitted by continental observers that the Pleistocene cave-deposits, tufas, lignites, and ossiferous river-alluvia that lie outside of the glaciated areas are the equivalents of the glacial and interglacial deposits of which I have been speaking. Every one knows that the mammals, molluscs, and plants met with in the former clearly indicate oscillations of climate. This testimony is on all fours with that furnished by the glacial and interglacial deposits. In short, the Pleistocene accumulations of extra-glacial regions are of the same age as the latter. Consequently German and French palæontologists do not now hesitate to describe the cave-accumulations and ossiferous alluvia as of glacial and interglacial age. From a study of these deposits and their organic remains we acquire a more comprehensive and definite conception of the climatic conditions of interglacial times. At the climax of the interglacial phase the climate differed materially from the temperate conditions that now obtain in Europe. It must have been indeed remarkably equable. In the latitude of Paris, for example, the laurel of the Canary Islands flourished, and as that plant flowers in winter, it is obvious that frosts must have been practically unknown. The flora of the period shows a strange commingling of species, such as we nowhere see to-day over an equally wide area of the earth's surface. Many plants, which are still indigenous in Southern France, flourished there side by side with species which no longer live in that region—some of these last having retreated because unable to support the cold of winter, while others have retired to the mountains to escape the dryness of summer. Similar evidence is forthcoming from the Pleistocene accumulations of Northern France, Italy, and Germany. In a word, clement winters and relatively cool and humid summers permitted the wide diffusion and intimate association of plants which have now a very different distribution—temperate and southern species formerly flourishing to-

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gether over vast areas of Central and Southern Europe. And similarly we find that during the same period the regions in question were tenanted by southern and temperate forms of animal life—(such as elephants, rhinoceroses, and hippopotamuses, together with cervine, bovine, and other forms, not a few of which are still indigenous to our continent)—that ranged from the shores of the Mediterranean up to our own latitudes.

3. Leaving the subject of glacial and interglacial conditions we may now glance very briefly at the evidence of climatic change in Postglacial times. The latest phase of the Pleistocene was a cold one. The upper boulder clay of Britain and Northern Europe and a series of great moraines in the Alpine lands and other mountain districts of Middle and Southern Europe were laid down during the last stage of the Pleistocene period. The earliest Postglacial beds are likewise indicative of cold conditions, but their geographical distribution and their organic contents are evidence that at the time of their accumulation the extreme glacial climate was passing away. I have elsewhere brought forward abundant evidence to show that after the final disappearance of cold conditions, the climate of North-western Europe eventually became genial. It was during those genial conditions that vast forests extended over regions which are now almost or entirely treeless. Those forests have left their relics underneath the oldest peat-bogs of North-western Europe, as far north as Northern Norway, and they occur also in the Orkney and Shetland Islands, in the Outer Hebrides, in the Færoes, and in Iceland. But I need not go into details. Suffice it to say, that from peat-bogs and alluvia, and from ancient raised beaches on both sides of the Atlantic, we have good evidence to show that during a certain stage in the Postglacial period forests of deciduous and coniferous trees had a much greater horizontal and vertical range than at present, while a larger body of warm water than now found its way into the North Atlantic. Later on, the climate changed and became less favourable to the growth of great forests while local glaciers reappeared in the higher mountain-valleys of Scotland, and here and there descended to the sea. The conditions, in short, became colder and wetter. Still later, somewhat similar but less strongly marked oscillations of climate would appear to have supervened, but this I need not here insist upon. These conclusions as to the climatic vicissitudes of Postglacial times have been independently arrived at by Professor Blytt, from a study of the Scandinavian peat-bogs; while Professor Penck has likewise detected in the Pyrenees evidence of the partial recrudescence of glacial conditions during the Postglacial period. Similar conclusions, I may add, have been reached by Dr

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Brückner from his observations in the Salzach region and in the south-east Alps; and by Dr Kerner from his study of the glacial deposits in the valley of the Stubai, a feeder of the Inn.

4. Lastly, I shall refer just in a word to the fact that changes in the relative level of land and sea are well known to have occurred both in Pleistocene and Postglacial times.

I have now summarised what appear to me to be the more important conclusions arrived at with regard to the physical conditions of those times. The Pleistocene period was characterised by extreme climatic changes and by oscillations of the sea level, while similar but less strongly-marked climatic and geographical vicissitudes took place in the succeeding Postglacial period. It goes without saying that any suggested explanation of these changes, which does not fully consider each, cannot be considered satisfactory. The problem before us is the framing of a theory which shall account as well for the genial interglacial as for the cold glacial phase of the Pleistocene period, and for the less pronounced but nevertheless clearly indicated climatic changes of succeeding Postglacial times. Now my first objection to the view which I am about to criticize is that it does not fulfil these conditions. Its chief object is to explain the occurrence of the cold climate of Glacial times —the interglacial phase is very inadequately treated, while there is no attempt made to account for the later Postglacial changes. The view to which I refer is that which we may term the "earth-movement hypothesis." Those who advocate it are of opinion that glacial conditions were induced by great continental elevations in the Northern Hemisphere. No one will doubt that, were Northern and North-western Europe, together with the corresponding latitudes of North America, to be greatly elevated, the mean annual temperature of all those regions would be reduced. But such elevation (even if it resulted in a land-connection between the two continents by way of the Færoe Islands, Iceland, and Greenland) would not affect to any marked degree the climate of Southern or even perhaps of Middle Europe. Still less would it influence that of North Africa, Syria, or Asia Minor, not to speak of the mountains of Central and Southern Asia and the highlands of China—in all of which the records of former extensive glaciation are visible. Nor can we believe that the postulated elevation of the northern latitudes of America could induce the appearance of large glaciers in the Sierra Nevada of California and the Sierra Madre of Mexico. With a continuous land-passage between Europe and North America no cold Arctic currents would flow into the Atlantic. On the other hand, the Gulf-stream would return upon itself, instead of being lost in Polar Seas. Thus a larger

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body of warm water would circulate in the North Atlantic. Under such circumstances Norway might be extensively glaciated, and considerable snowfields might be generated in the mountains of Britain, but it is impossible that the snowline of Central and Southern Europe could be lowered to the extent of 3000 feet, as we know was the case in Glacial times. The elevation required to bring about a lowering of the snowline for 3000 feet must needs have been general—the entire continent of Europe must have been upheaved. And not only so but North Africa and large areas of Asia and North America must likewise have been greatly elevated. But for such elevation (highly improbable in itself) there is no evidence whatsoever.

It is true we have good reason to belief that North-western Europe has experienced considerable submergence. The fiords of Norway and the sea-lochs of Scotland are unquestionably old land-valleys. They are hollows of erosion, excavated by running water, and, therefore, they tell of a time when Scandinavia extended considerably further out into the Atlantic, while the British Islands were united to themselves and the Continent. To convert all the existing fiords, including the Skager Rak, into dry land would necessitate an elevation of more than 2500 feet—probably not less than 3000 feet. Similar drowned valleys occur along the coasts of North America, and in these soundings varying from 1000 feet to nearly 4000 feet have been obtained. No doubt our fiords have been modified to some extent by glacial action, but it is quite certain that they were all in existence long before the Glacial period, and therefore they do not afford us any evidence as to the relative position of land and sea at the advent of glacial conditions. To assert that North Western Europe and the corresponding regions of North America stood some 2500 or 3000 feet higher than at present at the time referred to, is to make an unwarrantable assumption. But even if we grant the assumption, it is hard to see how it can help the hypothesis I am considering. Is it not perfectly certain that the fiord-valleys being of subaërial origin, their erosion implies a vast lapse of time? During all that time, notwithstanding the elevation of the land, streams and rivers were the chief excavators of its surface. It was not until the great work of erosion had been well-nigh completed that glacial conditions supervened. Let me emphasise this point, for it is important. The fiords of North America and North-west Europe are drowned land-valleys—they were excavated by running water, and other subaërial agents long before the Glacial period. The former greater elevation of the land to which they testify must, therefore, have been maintained for a protracted period of time without inducing glacial conditions. I repeat, then, that

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the evidence of the fiords as to a former greater elevation of the land has no bearing whatever on the question of glacial climate.

But let us ask what we do really know of the geographical conditions that obtained in times immediately preceding the Ice Age. We may go back as far as the Pliocene period. During the accumulation of the Pliocene beds, the sea overflowed the south-east of England and encroached upon the north-east of Scotland. We have every reason, in short, to believe that the North Sea was in existence at that time. Pliocene deposits also occur in the extreme south of England—so that we cannot doubt that in those days the British land-area did not extend quite so far as now to the east and south. I need not here do more than mention the well known fact that the maritime districts of the Mediterranean were likewise, in Pliocene times, submerged to a very considerable extent. Take another fact. The younger Pliocene deposits of Suffolk and Norfolk afford evidence to show that cold climatic conditions gradually supervened towards the close of the period. In other words, a cold climate ensued while the land was at a lower level than it is to-day. It may be said, however, by the supporters of the earth-movement hypothesis, that the upheaval, which, according to them, induced glacial conditions, probably began in the north, and subsequently extended southward. But what are the facts? The till of Northern Scotland, as in Lewis and Caithness, is often crowded with crushed and broken shells of boreal and temperate species. Obviously in times immediately preceding the Ice Age, the Scottish coasts were washed by the sea. And it is further noteworthy that marine shells occur in like manner in the till of the coast of South Ayrshire, as well as in that at Berwick. Nor in this connection can one avoid referring to the similar occurrence of sea-shells in the boulder-clays on both sides of the Irish Sea, and to their appearance in the "diluvium" of Denmark, and the Baltic Provinces of Prussia. So far as the facts go we are justified in believing that at the advent of glacial conditions in North-west Europe, the distribution of land and sea was much the same as it is now. The notion that the land was greatly elevated at that time is, as I have said, a mere assumption. Here, however, I am reminded of the occurrence of our pre-glacial river-channels, some of which go out to sea, and prove that at the time of their excavation our area probably stood 300 feet or so higher than now. I have seen many of those old stream- and river-courses in various parts of Scotland, and the general impression I have gathered from them is that just before Glacial times our streams and rivers were much the same as they are now. They flowed, however, at a somewhat lower level

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than their present representatives—in other words, the land in preglacial times had a somewhat greater elevation, but probably did not exceed its present height by more than 300 feet. But when the Scottish ice first flowed out from the mainland, that mainland was then as at present washed on the east by the North Sea, while on the west it was separated from the Outer Hebrides by the waters of the Minch. In short, a review of all that is known of the glacial deposits of the maritime regions of North-west Europe leads to the conviction that the distribution of land and sea was much the same at the beginning of the Glacial period as it is to-day. We note further also that there is abundant evidence of land-submergence during Glacial times. Indeed, we may say, that the Pleistocene marine deposits of northern latitudes are almost invariably indicative of colder conditions than now obtain.

If it be true that cold climatic conditions were contemporaneous in our latitude with submergence, it is equally true that an extensive land-surface in North-west Europe has sometimes, at least, co-existed with markedly genial conditions. In Tertiary times, for example, as the Oligocene deposits of Scotland, the Færoe Islands, Iceland, and Greenland testify, a land-connection existed between Europe and North America. Again, it has been shown that during the interglacial phase of the Pleistocene period Britain was continental, and enjoyed at the time a peculiarly genial climate. And somewhat similar geographical and climatic conditions again supervened in Post-glacial times. In other words, when the land was more elevated and extensive than now, it enjoyed a warmer climate. Nor can we escape the conclusion that the excavation of the fiord-valleys of northern latitudes, which is a very old story (far older than the Pleistocene), was the work not of glaciers but of running water, at a time when North-western Europe and the corresponding regions of America were much more elevated than they are now.

Other arguments might be advanced against the "earth-movement hypothesis" as an explanation of the cold climate of the Glacial period, but what I have said may suffice to show that this hypothesis is unsupported by facts. It is merely a guess, and even if it could be proved that the northern latitudes of our continent and of North America were much more elevated in Glacial times, such land-conditions would not account for the phenomena of the period.

It has been suggested, however, that the cold conditions of the Glacial period may have been caused by the escape of the great Equatorial current across the Isthmus of Panama. A submergence of that Isthmus, if sufficiently great, would

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doubtless enable the large body of heated water which now circles round the Gulf of Mexico and issues through the Straits of Florida to flow into the Pacific.[1] There is no proof, however, of any such disconnection of the two Americas having taken place in Pleistocene times. Mr Jukes-Browne and Professor Harrison have recently re-advanced this view, but the grounds upon which their inferences are based seem to me to be quite inconclusive. That there has been, within a comparatively recent geological period, great depression and re-elevation within the area of the Caribbean Sea may be admitted; but so far as the evidence goes, the movement of depression may quite well have taken place in Pliocene times, and there are no facts forthcoming to show that the Isthmus of Panama was contemporaneously drowned to such an extent as to allow the passage across it of the Equatorial current. But even if it could be demonstrated that in Pleistocene times no Gulf-stream flowed into the North Atlantic, we should not yet have hit upon the explanation of the Glacial period. In the absence of a Gulf-stream, the climate of the maritime districts of Western Europe and Eastern North America would no doubt be disastrously affected—Norway would be uninhabitable, and glaciers might well come into existence amongst the mountains of Britain. But no change in Atlantic currents could sensibly influence the climate of South-eastern Europe and Asia; still less could the disappearance of the Gulf-stream induce extensive glaciation in the Rocky Mountains and the Pacific coast-lands of North America.

Some supporters of the "earth-movement hypothesis," suspecting, apparently, that mere upheaval of the land in northern latitudes might not, after all, account for the Glacial period, have cast covetous eyes upon the Isthmus of Panama. If it could only be shown that during Glacial times that Isthmus did not exist, then the whole mystery of glacial climate would be solved! With the higher latitudes of North America and Northern Europe upheaved some 3000 feet above their present level, and with the Isthmus of Panama submerged, one cannot doubt that the climate of Eastern North America, and still more that of Western Europe, would be profoundly modified. A large proportion of North-west Europe would be uninhabitable. But to what extent it would be covered with perennial

[1] In order to deflect the Equatorial current into the Pacific, not only the Isthmus of Panama, but a considerable portion of Central America, would need to be deeply submerged. It may even be doubted whether, in the event of such submergence taking place, any considerable proportion of the Equatorial current would flow into the Pacific. It seems just as probable that the Counter current of the Pacific would escape into the Caribbean Sea, and thus increase the body of the Equatorial current.

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snow it is hard to say; for we must remember that the extensive snow-fields and ice-sheets of the Glacial period imply not only a lower temperature, but a greater precipitation for the regions involved. It is most probable, however, that, under the supposed geographical conditions, precipitation would be less than at present. Nor is it likely that the waters of the North Atlantic would be chilled to such an extent as they would be were the Gulf-stream to disappear while free communication with Polar seas subsisted. With a land-passage joining Europe to America no Arctic current could find its way into the North Atlantic. The latter would then form an immense gulf round which, doubtless, there would be a circulatory current-movement, in which the tropical waters would participate. The heating effect of the Gulf-stream would be lost, but this, to some extent at least, would be compensated by the absence of cold water from Polar seas. Under such conditions it seems most probable that the climate of South-western Europe would be less affected than if the Gulf-stream were to be withdrawn while the present open communication with Polar seas continued to be maintained.

A still further objection to the earth-movement hypothesis, whether restricted to the elevation of land in northern latitudes or to the submergence of Panama, or embracing both movements together, lies in the fact that we have more than one epoch of glaciation to account for. To explain the recurrence of glacial conditions at successive stages of the Pleistocene and Postglacial periods we should be compelled, on that hypothesis, in any of its forms, to postulate several earth-movements. We should have to suppose that a vast area of the earth's crust periodically rose and fell during what was after all a comparatively short period of time.

Having shown that we have no proof that the land in northern latitudes was greatly elevated at the beginning of the Pleistocene period, and no evidence that the Isthmus of Panama was submerged in Glacial times; and having further pointed out that the known conditions of the glaciated tracts of the Northern Hemisphere cannot be explained by this earth-movement hypothesis, we may next inquire how far it throws any light on interglacial phenomena.

Now, according to the hypothesis in question, interglacial conditions could only have resulted from depression of the land in high latitudes, combined probably with the re-appearance of the Isthmus of Panama. But these are precisely the conditions that now obtain, and yet, in spite of them, the climate at present experienced in Europe is not the same as that of interglacial times. The seasons are to-day more sharply-contrasted than

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they could possibly have been while the remarkable interglacial flora and fauna flourished in our continent. The climate of that stage was obviously more genial and equable than ours. Nor can we doubt that in the Postglacial period there was for a time something like a return to the same genial conditions in North-western Europe. I have elsewhere endeavoured to show that, during the mild postglacial stage, a considerably larger body of warm water poured into the North Atlantic than is now the case. The character of the organic remains met with in certain raised beaches on both sides of the Atlantic renders this highly probable, and the notable occurrence in northern seas of isolated colonies of southern molluscs is additional evidence leading to the same conclusion. The inference, therefore, is that, during the genial postglacial and interglacial epochs, the waters of the North Atlantic were considerably warmer than now. But how shall we explain the greater influx of warm water by any form of the earth-movement hypothesis? And if we reject the suggestion that the singularly equable character of the interglacial climate was probably due to a warmer North Atlantic, how otherwise can it be accounted for? What possible application of the earth-movement hypothesis throws any light whatsoever upon the origin or cause of interglacial conditions? I do not wonder that the existence of interglacial deposits has proved to be somewhat of a stumbling-block in the way of that hypothesis, and that its supporters have either sought to minimise the importance of the deposits in question, or altogether ignored them. They have striven to explain the origin of a glacial climate as if that were the only abnormal phase of the Pleistocene period that required consideration. And yet, if we think of it, the peculiar character of the interglacial climate is, from the point of view of the present, just as much of an anomaly as that of Glacial times. Those who maintain that the interglacial beds indicate only unimportant oscillations of the ice-sheets and glaciers have not, as it seems to me, fairly considered what the evidence really means. Is it possible to believe that, at the climax of interglacial times, when the Canary laurel and its congeners flourished in Northern France, and when the hippopotamus and other southern and temperate forms tenanted England and the corresponding latitudes of Middle Europe — is it possible to conceive that at such a time the snow-fields and glaciers of Europe could have been more extensive than they are at present? Yet, if I understand certain upholders of the earth-movement hypothesis aright, their notion is that, while an ice-sheet reached into North Germany, a temperate flora and fauna lived in its immediate neighbourhood, so that when the ice retreated locally for a short distance, the flora

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and fauna eventually usurped the vacated area, which some time afterwards was again invaded by ice. If the interglacial flora and fauna were invariably Arctic-alpine in character, such a view might seem not unreasonable. And if, moreover, it could be shown that no great erosion and denudation were effected during interglacial times, the explanation would receive yet stronger support. But the evidence of such interglacial beds as those of Italy and Bavaria, of North Germany, Central Russia, and France is fatal to it. The general conclusion arrived at by geologists who are familiar with the phenomena of our interglacial accumulations is that these indicate a well-marked and decided stage of the Pleistocene period, a stage of long duration, characterised by a climate which, at first cold and arctic, gradually became extremely genial, and subsequently deteriorated as the last cold epoch of the Pleistocene approached.

For these and for other reasons that the limits of an address will not permit me to give, I consider that the earth-movement hypothesis fails to explain the climatic conditions of either glacial or interglacial times.

There is yet another physical condition of the Pleistocene and Postglacial periods which any adequate explanation must embrace. I refer to the oscillation of sea-level, of which so many proofs are forthcoming. It is very remarkable that almost everywhere throughout the maritime regions of formerly glaciated areas we find evidence of submergence. So commonly is this the case, that geologists have long suspected that the connection between glaciation and submergence might be one of cause and effect. The possible influence of great ice-sheets in disturbing the relative level of land and sea is a question, therefore, of very great importance. It is one, however, which must be solved by physicists. Croll and others have advocated the view that the great accumulations of ice of the Glacial period may have displaced the earth's centre of gravity, and thus caused the sea to rise upon the glaciated hemisphere. The various results arrived at by physicists are hardly comparable, because each has used different data, but it seems probable that we have in this view a *vera causa* of oscillations of the sea-level. Another hypothesis would explain the rise of the sea as due to the attractive influence of the great ice-masses, but Dr Drygalski's elaborate investigation would seem to have demonstrated that this notion does not account for the facts. Yet another speculation has been advanced. Mr Jamieson has suggested that the mere weight of the ice-sheets would suffice to press down the earth's crust into a supposed liquid substratum, and this explanation has met with much acceptance. Unfortunately our knowledge of the condition of the earth's interior is so very limited that we cannot be

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certain as to how the crust would be affected by the weight of an ice-sheet. No doubt Mr Jamieson's hypothesis gives a specious explanation of certain geological phenomena, but, if there be no liquid substratum underlying a thin crust, it cannot be true. At present the prevalent view of physicists appears to be that the earth is substantially solid. Professor George Darwin has shown that the prominent inequalities of the earth's surface could not be sustained unless the crust be as rigid as granite for a depth of 1000 miles. "If the earth be solid throughout," he remarks, "then at 1000 miles from the surface the material must be as strong as granite. If it be fluid or gaseous inside, and the crust 1000 miles thick, that crust must be stronger than granite, and if only 200 or 300 miles in thickness, much stronger than granite. This conclusion is obviously strongly confirmatory of Sir William Thomson's view, that the earth is solid throughout." But, as you are aware, many geologists find it hard to account for the convolutions of strata and other structural phenomena, on the supposition that the earth is entirely solid, and they are inclined, therefore, to adopt the hypothesis of a sub-crust layer of liquid matter. Whether this be actually the condition or not physicists must be left to determine. All that we need note is, that if there be any force in Professor Darwin's argument, it is obvious that the crust is possessed of great rigidity, and could not be readily deformed by the mere weight of an ice-sheet. According to Dr Drygalski, however, the presence of an ice-sheet, by reducing the temperature of the underlying crust, would bring about contraction, and in this way cause the surface to sink. When the ice-sheet had disappeared, then free radiation of earth-heat would be resumed, the depressed isogeotherms would rise, and a general warming of the upper portion of the lithosphere would take place. But the space occupied by the depressed section, owing to the spheroidal form of the earth, would be smaller than that which it occupied before sinking had commenced, and consequently when the ice vanished expansion of the crust would follow, and the land-surface would then rise again. The whole question is one for physicists to decide upon, but I may point out that if Drygalski's explanation be well-founded, then it is obvious that it throws no light upon the origin and subsequent disappearance of an ice-sheet. Somehow or other this ice-sheet comes into existence, and the cooling and contracting crust sinks below it; and that depressed condition of the glaciated area must continue so long as the ice-sheet remains unmelted. Re-elevation can only take place, when, owing to some other cause or causes, the climate changes, and the ice-sheet vanishes.

Those who advocate the earth-movement hypothesis as an

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explanation of the origin of extensive glaciation have welcomed Mr Jamieson's view as harmonising well with their conclusions. They contend, as we have seen, that glacial conditions were induced by an extensive upheaval of the crust in northern latitudes, accompanied by a depression of the Isthmus of Panama. They then proceed to point out that the ice-sheets brought about their own dissolution by pressing down the crust, and introducing with submergence a disappearance of glacial conditions. See now how much they take for granted. In the first place, they assume an amount of preglacial or early glacial elevation of northern regions for which not a scrap of evidence can be adduced, while they can give no proof of contemporaneous depression of the Isthmus of Panama. Next, relying on Mr Jamieson's hypothesis, they take for granted that the ice-sheets, called into existence by their postulated earth-movements, succeeded in depressing the earth's surface even below its present level. That is to say, the land, which, according to them, was in glacial times some 3000 feet higher than now, sank down under the weight of its glacial covering for, say, 3600 feet in North-western Europe. In North America, in like manner, all the preglacial elevation was lost—the land sinking below its present level for some 200 feet in New England, for 520 feet at Montreal, for 1000 to 1500 feet in Labrador, and for 1000 to 2000 feet in the Arctic regions. Now, even if we concede the reasonableness of Mr Jamieson's hypothesis, and admit that a certain degree of deformation may take place under the mere weight of an ice-sheet, it is difficult to believe that the crust can be so readily deformed as the supporters of the earth-movement hypothesis seem to imply. If it could yield so readily to pressure, one is at a loss to understand how a great ice-sheet could accumulate—the ice would simply float off as the land subsided. Take the case of North-western Europe. The ice-sheet that covered Scotland did not attain, on the average, 3000 feet in thickness, and yet we are to suppose that it was able to depress the land for some 600 feet below its present level—that is to say, for 3600 feet below its assumed preglacial elevation. Either the ice depressed the crust to that remarkable extent, or the land upon which the ice accumulated was not nearly so high as the advocates of the earth-movement hypothesis have supposed. But the average I have taken for the thickness of the Scottish ice-sheet is excessive, for it was only in the low grounds that the *mer de glace* attained such a depth. A large part of our country, however, is mountainous, and the mountain-tops were, of course, not nearly so thickly mantled with ice as the valleys. And the same to even a larger extent holds good for the Scandinavian peninsula. If we take the thickness of the Scandinavian ice-

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sheet that coalesced with that of Scotland as 4000 feet, we shall be over the mark. Now, I ask, is it possible to believe that a sheet of ice of that thickness actually pressed down the crust of the earth for not less than 3600 feet? But if we accept the earth-movement hypothesis, as it has been recently advocated, that is what we must believe. If we cannot do so, then we cannot accept the assumption of great elevation of the land in preglacial and glacial times. Let me put the case shortly: if the glacial marine beds and raised beaches of the Atlantic borders of Europe and North America owe their origin to depression induced by the weight of an ice-sheet, then it is quite certain that at the advent of glacial conditions the land could not have been so highly elevated as the advocates of the earth-movement hypothesis suppose. But if we are to accept the notion of great elevation of the land, then we must conclude that the submergence to which the raised beaches testify cannot have been caused by the pressure of ice-sheets.

It is hardly necessary to pursue this particular subject further, but before leaving it, attention may be drawn for a moment to the curious conclusion that the ice-sheets were self-destructive. One is left to guess at what particular stage the sinking process began; but if the earth's crust were as readily deformed as the extreme views I have been examining would compel one to imply, then depression must have commenced almost immediately with the accumulation of snow and ice. The several ice-sheets must soon have attained their maximum thickness, and their disappearance must have been correspondingly rapid. And yet all the evidence goes to show that a glacial epoch endured for a comparatively long time—for a time sufficient to account for a prodigious amount of rock-erosion, and for the accumulation of vast sheets of glacial debris and fluvio-glacial detritus.[1]

If it be difficult to understand how the earth-movement hypothesis can account for the origin of one glacial epoch, the difficulty is not lessened when we remember that there are two or more such epochs to account for. And until the advocates of that hypothesis can furnish us with some reliable evidence, they can hardly expect us to believe in their mysterious upheavals and depressions of northern and temperate regions, and in the no less wonderfully rhythmic movements of the Isthmus of Panama. In fine, the views which I have

[1] It must not be inferred from the above remarks that I deny the possibility of deformation of the crust having been induced by the old ice-sheets. The geological evidence is certainly suggestive of such having been the case. But I much doubt whether the sinking of the surface was brought about by the mere weight of the ice pressing the crust down into a subjacent liquid layer. Dr Drygalski's explanation seems less objectionable, and would better account for the geological phenomena.

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been controverting seem to me to be untenable, inasmuch as they are founded on mere assumptions, and do not even give a reasonable and intelligible explanation of the phenomena of glaciated regions, while they practically ignore or leave unsolved the problem of interglacial conditions.

Some five-and-twenty years have now elapsed since my lamented friend and colleague, James Croll, published his well-known physical theory of the Glacial period. That theory, as you all know, has been frequently criticised by physicists and others, to whose objections Croll made a final reply in his "Climate and Cosmology." In that work he has successfully defended his views, and even added considerably to the strength of his general argument. I am not aware that since then any serious objections to Croll's theory have appeared. The only one indeed that seems to have attracted attention is that which has been urged specially by certain American geologists. Their belief is that the close of the Glacial period must have taken place at a much more recent date than Croll has inferred. And this belief of theirs is based upon various estimates which have been made as to the time required for the erosion of valleys and the accumulation of alluvial deposits since the Glacial period. Thus, according to Mr Gilbert, the Postglacial gorge of Niagara, at the present rate of erosion, must have been excavated within 7000 years; while Mr Winchell, from similar measurements of the Postglacial erosion of the Falls of St Anthony, concludes that 8000 years have elapsed since the close of the Ice Age. I might cite a number of similar estimates that tend to show that since the close of the Glacial period only 7000 or 10,000 years have elapsed. What will Archæologists say to this conclusion? We know that Egypt was already occupied by a civilised people nearly 6000 years ago, and their marvellously advanced civilization at that time presupposes, according to Egyptologists, many thousands of years of development. Are we, then, prepared to admit that the close of the Ice Age coincided with the dawn of Egyptian civilization? But all American observers are not so parsimonious with regard to Postglacial time. Thus Professor Spencer has given the age of the Falls of Niagara as 24,000 years, and he informed me recently that this does not represent half of the time since the formation of the third great series of glacial deposits of the Canadian uplands. In our own Continent similar estimates have been based on the rate of erosion of river-valleys, the rate of accumulation of alluvial deposits, of peat-bogs, of stalagmite in caves, and what not, with results that, to say the least, are rather discordant. The fact is that all such measurements and estimates, however carefully conducted and cautiously made,

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are in the nature of things unreliable. We are insufficiently acquainted with all the factors of the problem to be solved, and I cannot therefore agree with those who attribute much weight to conclusions based on such uncertain data. Dr Croll's theory may eventually be modified, but I feel sure that it will not be overturned by the inconclusive and unsatisfactory estimates to which I have referred. Moreover, opponents of that theory may be reminded that its truth does not rest on the accuracy of its author's conclusion as to the date of the last Ice Age. That periods of high eccentricity of the earth's orbit have occurred is beyond all doubt, but whether the formulae employed by Croll in calculating the date of the last great cycle can be relied upon for that purpose is quite another question.[1] At present, so far as I understand the facts, the glacial and interglacial phenomena are explained by the astronomical theory, and by no other. It gives a simple, coherent, and consistent interpretation of the climatic vicissitudes of the Pleistocene and Postglacial periods, and in especial it is the only theory that throws any light on the very remarkable climates of interglacial times.

[1] Since this address was given Sir Robert Ball's extremely interesting work —"The Cause of an Ice Age"—has appeared. The author makes no attempt to estimate the date of the last glacial epoch; the formulae employed in forming such estimates being according to him unreliable for such an extreme application as has been demanded of them.

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY,

SESSION 1891-92.

XXVII.—*The late Sir Andrew Crombie Ramsay, LL.D., F.R.S., &c. (with Photograph).* By Prof. JAMES GEIKIE, D.C.L., LL.D., *President.*

(Read 18th February 1892.)

THE subject of this notice was born in Glasgow in 1814, being the son of William Ramsay, a manufacturing chemist of considerable originality, who distinguished himself by the invention of several processes for the manufacture, on a large scale, of various chemical products. Andrew was educated in his native city, and for some years was engaged in uncongenial commercial pursuits. Eventually, however, he was induced, by a perusal of such works as Scrope's "Volcanoes of Central France" and Lyell's "Principles of Geology," to devote his attention to the stony science. The opportune meeting of the British Association at Glasgow in 1840 was the means of introducing him to the leading geologists of the day. In preparation for that meeting he had completed a geological map and model of the island of Arran, which were much admired, and particularly arrested the attention of Mr (afterwards Sir) Roderick Murchison. In 1841, at Murchison's invitation, Ramsay went to London, where he was introduced to Mr (afterwards Sir) Henry de la Beche, director of the Geological Survey, then in its infancy, from whom he accepted the post of Assistant-Geologist. In the same year he published his first work, "The Geology of Arran," which at once gained for him a great reputation. Geology advances at such a rapid pace, that a work now fifty years old must necessarily seem crude if judged by

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the standard of our present knowledge. But those who are acquainted with the geological literature of half a century ago can well understand how Ramsay's "Arran" came to take its place in the front rank of works dealing with physical geology. It everywhere betokens the keen observer, and, like all his subsequent writings, is characteristically suggestive. The main features in the structure of the island were firmly grasped, and illustrated in the clearest and most graphic manner. His style is neither elaborate nor polished, but easy and unconstrained, while now and again, when he has occasion to refer to the scenery, he becomes picturesque and even poetical. Of his early years on the Survey Ramsay always spoke with fond enthusiasm. The life was delightful, and many a tale he had to tell of the happy family over which De la Beche presided as guide, philosopher, and friend. Amongst his associates in the Survey at the time were Edward Forbes, Warrington Smyth, Robert Hunt, Henry W. Bristow, all of whom have passed away; W. Talbot Aveline, and Alfred Selwyn, now Director of the Geological Survey of Canada. It was in Wales that Ramsay commenced his work for the Survey, a region which was then very imperfectly known to geologists. Only those who have gone over Wales with the maps and sections of the Geological Survey in their hand can realise the arduous labour and the great skill and acumen with which the unravelling of the complicated structure of the Welsh mountains was completed by Ramsay and his colleagues. So greatly had Ramsay's powers impressed De la Beche, that when, in 1845, the Survey was reorganised, and Sir Henry became Director-General, Ramsay was appointed Local Director for Great Britain. In addition to that official post, he was, in 1848, called to the Chair of Geology in University College, London, which he resigned in 1851, on his appointment to the professorship at the Royal School of Mines—a position which he retained for the long term of twenty-six years. Ramsay had lived so much in Wales, and met with so much kindness there, that he cherished for it an affection equal to his love for his native land. He was full of Welsh lore, traditions, and antiquities, and used stoutly to maintain that the outline of the Welsh mountains, as seen from Anglesey, was the finest view of the kind in Britain. It was in that island that he found his wife, a daughter of the Rev. Chancellor Williams of Llanfairynghornwy. On the death, in 1872, of Sir Roderick Murchison, who had succeeded Sir Henry de la Beche, Ramsay became Director-General of the Geological Survey.

In the course of his career Ramsay took every opportunity of widening his knowledge by travel. His holidays for many

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years were spent upon the Continent—Switzerland being one of his favourite hunting grounds. In 1857, as a delegate of the Geological Society, he attended the meeting of the American Association for the Advancement of Science, and became acquainted with the glaciated regions of the States and Canada. Trained as he had been in field work, those holiday journeys were made the most of—his quick eye missing nothing, so that in a traverse he could diagnose the structure of a region with a rapidity impossible to one with less experience and penetrating skill. In 1876, at the request of the Colonial Office, he visited Gibraltar for the purpose of reporting on the water supply for the town and garrison. I had the privilege of accompanying Ramsay on that occasion, and can well remember the lively delight he took in working out the geological structure of the Rock and the adjacent parts of Spain, together with that of the opposite African coast. He had told me many years before that he had long had a strong desire to trace the origin and history of the Mediterranean depression. It was a subject, indeed, that he often recurred to in conversation, and he was full of it during our stay in Gibraltar. As he had been a devoted student of glacial geology all his life, he was much impressed with the evidence of the action of frost which we saw in the remarkable breccias of the Rock. Up to this time Ramsay had enjoyed, upon the whole, good health; he was never so well and happy, however, as when he could escape from town. To the last he wearied for the passing of winter, when he might again set off on his tour of inspection. These visits to his associates both they and he looked forward to with equal pleasure. Sincere, therefore, was the regret of his colleagues when, in 1881, failing strength induced their much-loved chief to resign. On his resignation Ramsay received the honour of knighthood. His health continuing to fail, he soon afterwards retired to Beaumaris, where, in the Welsh country which had been the scene of his early achievements, and in which he had spent the happiest years of his life, he passed away on the 9th of December 1891. He is survived by his widow and one son and four daughters.

Ramsay enjoyed most of the honours to which a geologist can attain. At an early date (1849) he was elected a Fellow of the Royal Society. In 1862 he became President of the Geological Society; in 1856, and again in 1881, he was President of the Geological Section of the British Association, and in the preceding year (1880) President of the British Association at Swansea. In 1866 the University of Edinburgh conferred upon him the honorary degree of LL.D. He has also been the re-

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cipient of various gold medals, as the Neill Medal (1866) of the Royal Society of Edinburgh, the Wollaston Medal (1871) of the Geological Society, and one of the Royal Medals (1879) of the Royal Society of London. His wide reputation secured him the honorary membership of many scientific bodies in Europe and America. He was also created by the Italian Government a Knight of the Order of SS. Maurice and Lazarus.

Ramsay was a born geologist, a diligent and acute observer, a highly original thinker, and a powerful exponent of his subject. No one ever surpassed him in the rapidity with which he could unravel the geological structure of a country. Nor was he less eminent for the power he had of vividly realising the various physical conditions which such a structure might imply. Well endowed with scientific imagination, he was able to marshal and group his facts, and to explain their meaning, in a way that was at once the admiration and the envy of others. To him science is largely indebted for the explanation and establishment of the now prevalent geological doctrines concerning denudation. His demonstration of the amount of rock which has been removed from the surface of North Wales by subaërial agents, and his delightful account of the origin of the surface-features of our country, form, indeed, conspicuous landmarks in the history of that department of physical geology. Among the most remarkable of his contributions to science are his papers that deal with glacial phenomena. His explanation of the origin of rock-basins by means of glacial erosion could only have been conceived by a master. The views he expressed on this subject were, of course, too original, too far in advance of the day, to be at once accepted, and gave rise to prolonged controversy at home and abroad. They may be said now to have triumphed. Theoretical questions always had for Ramsay an engrossing charm, and his writings in which these are discussed never fail to be highly suggestive. They have, indeed, a kind of inspiration for the thoughtful student—the subjects are treated with such breadth and power. Dowered with abounding vitality and enthusiasm, and fully conscious of his strength, Ramsay was yet the least self-assertive and the most modest of men. Young geologists were always sure of his sympathy and assistance. He would listen to what they had to say on some controverted subject with as much attention as he could possibly have given to an expert. It is no wonder, then, that he endeared himself to his old pupils and associates, who feel that with him some of the light of life has gone. He leaves behind him the memory of a highly-endowed and accomplished devotee of science—a genial, warm-hearted, and wholly lovable man.

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The following is a list of Ramsay's scientific works :[1]—

1840. Notes taken during the Surveys for the Construction of the Geological Maps and Sections of the Island of Arran. *British Association Report*, 1840 (Part II.), pp. 92-94.

1841. The Geology of the Island of Arran, from Original Survey. 8vo, pp. 78.

1846. On the Denudation of South Wales and the adjacent Counties of Wales. *Memoirs of Geological Survey*, Vol. I. pp. 297-335.

1847. On the Origin of the existing Physical Outline of a portion of Cardiganshire. *British Association Report*, 1847 (Part II.), pp. 66-69.

1848. On some Points connected with the Physical Geology of the Silurian District between Builth and Pen-y-pont, Radnorshire. *British Association Report*, 1848 (Part II.), p. 73.

1850. On the Physical Position of the Black Slates of Menai Straits, &c. *British Association Report*, 1850 (Part II.), p. 102.

1852. On the Superficial Accumulations and Surface-markings of North Wales. *Quarterly Journal of Geological Society*, Vol. VIII., pp. 371-376.

1853. On the Physical Structure and Succession of some of the Lower Palæozoic Rocks of North Wales and part of Shropshire, with Notes on the Fossils by J. W. Salter. *Quarterly Journal of Geological Society*, Vol. IX., pp. 161-176.

1854. On the Former Probable Existence of Palæozoic Glaciers. *British Association Report*, 1854 (Part II.), pp. 93-94.

On the Thickness of the Ice of the Ancient Glaciers of North Wales, and other Points bearing on the Glaciation of the Country. *British Association Report*, 1854 (Part II.), pp. 94-95.

On the Geology of the Gold-bearing District of Merionethshire. *Quarterly Journal of Geological Society*, Vol. X., pp. 242-247.

On Certain Peculiarities of Climate during part of the Permian Epoch. *Proceedings of the Royal Institution, London*, Vol. II., pp. 417-421.

On the Geological Causes that have influenced the Scenery of Canada and the North-Eastern Provinces of the

[1] Ramsay was a not infrequent contributor to the *Saturday Review* and other periodicals on various topics, social and literary. He had, indeed, a fine literary taste, and a tenaceous memory, especially for poetry. When he was in a particularly happy mood he quoted freely and aptly,—most frequently from Shakespeare, Keats, and the Border Ballads. He was full also of a quiet humour, which often took the form of the quaintest remarks and the most ludicrous travesties of familiar sayings.

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United States. *Proceedings of the Royal Institution, London*, Vol. II., pp. 522-524.

1855. On the Occurrence of Angular, Subangular, Polished, and Striated Fragments and Boulders in the Permian Breccia of Shropshire, Worcestershire, &c., and on the Probable Existence of Glaciers and Icebergs in the Permian Epoch. *Quarterly Journal of Geological Society*, Vol. XI., pp. 185-205.

1858. The Physical Structure of Merionethshire and Carnarvonshire. *Geologist*, 1858, pp. 169-174.

1859. On Some of the Glacial Phenomenons of Canada and the North-Eastern Provinces of the United States during the Drift Period. *Quarterly Journal Geological Society*, Vol. XVI., p. 200-215. *Canadian Naturalist*, Vol. IV. pp. 325-342.

1860. The Old Glaciers of Switzerland and North Wales. London. 8vo, pp. 116. (Originally published as one of the chapters in "Peaks, Passes, and Glaciers," &c., edited by John Ball.)

The Physical Geology and Geography of Great Britain. 8vo.

1862. On the Glacial Origin of certain lakes in Switzerland, the Black Forest, Great Britain, Sweden, North America, and elsewhere. *Quarterly Journal Geological Society*, Vol. XVIII., pp. 185-204. *Silliman's Journal*, Vol. XXXV, pp. 324-346.

The Excavation of the Valleys of the Alps. *Philosophical Magazine*, Vol. XXIV, pp. 377-380.

1863. Breaks in Succession of the British Palaeozoic Strata. *Quarterly Journal Geological Society*, Vol. XIX., pp. xxxvi.-liii.

1864. On the Transitions between the Sub-divisions of the Lias and the Oolite in England. *American Journal of Science*, Vol. XXXVIII, pp. 285-287.

On the Erosion of Valleys and Lakes. *Philosophical Magazine*, Vol. XXVIII., pp. 293-311.

1865. Sir Charles Lyell and the Glacial Theory of Lake Basins. *Philosophical Magazine*, Vol. XXIX., pp. 285-298.

On the Eozoon and the Laurentian Rocks of Canada. *Proceedings of the Royal Institution, London*, Vol. IV. pp. 374-377.

1866. Address to the Geological Section of the British Association. *British Association Report*. 1866. (Sect.) pp. 46-50. *Geological Magazine*, Vol. III., pp. 508-514.

The Geology of North Wales. *Memoirs of Geological Survey*, Vol. III., pp. 381.

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1871. On the Physical Relations of the New Red Marl, Rhætic Beds, and Lower Lias. *Quarterly Journal Geological Society*, Vol. XXVII., pp. 189-198. *Philosophical Magazine*, Vol. XLII., pp. 76-77.

On the Red Rocks of England of Older Date than the Trias. *Quarterly Journal Geological Society*, Vol. XXVII., pp. 241-254. *Philosophical Magazine*, Vol. XLII., pp. 228-230.

1872. On the River-Courses of England and Wales. *Quarterly Journal Geological Society*, Vol, XXVIII., pp. 148-160.

On the Recurrence of Glacial Phenomena during great Continental Epochs. *Nature*, Vol. V., pp. 64-65.

1873. On Old Continents. *Proceedings of the Royal Institution, London*, Vol. VII., pp. 32-34.

On the Comparative Value of certain Geological Ages (or groups of formations) considered as Items of Geological Time. *Proceedings of Royal Society*, Vol. XXII., pp. 145-148, 334-343.

1874. The Physical History of the Valley of the Rhine. *Quarterly Journal Geological Society*, Vol. XXX. pp. 81-93.

Geology: Article in Popular Encyclopaedia. (London.) Vol. VI., pp. 583-713.

1875. Geological History of some of the Mountain Chains and Groups of Europe. (Lectures at the Royal School of Mines). *Mining Journal*, Vol. XLV.. pp. 57, 79, 106, 133, 162, 191.

The Pre-Miocene Alps and their Subsequent Waste and Degradation. *Proceedings of Royal Institution*, Vol. VII., pp. 455-457.

1876. How Anglesey became an Island. *Quarterly Journal Geological Society*, Vol. XXXII., pp. 116-122.

On the Physical History of the Dee, Wales. *Quarterly Journal Geological Society*, Vol. XXXII., pp. 219-229.

On the Origin of Lake Basins. *Geological Magazine*, Decade II., Vol. III., pp. 136-138.

The Origin and Progress of the Geological Survey of the British Isles, and the method on which it is conducted. Science Conferences held in connection with the Special Loan Collection of Scientific Apparatus. 2 vols, 8vo, London.

1877. The existence of Coal beneath the New Red and Permian Strata. *Proceedings Dudley Geological Society*, Vol. III., pp. 35-37.

1878. The Physical Geology and Geography of Great Britain. 5th and last edition largely added to.

The Geology of Gibraltar and the opposite coast of Africa; and the History of the Mediterranean Sea. *Proceedings of Royal Institution, London*, Vol. VIII., pp. 594-601.

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1880. On the Recurrence of certain phenomena in Geological Time. *British Association Report*, 1880, pp. 1-26 ; *Nature*, Vol. XXII., pp. 383-390.

1881. On the Origin and Progress of the Present State of British Geology, especially since the First Meeting of the British Association at York in 1831. *British Association Report*, 1881, pp. 605-608. *Nature*, Vol. XXIV., pp. 419-420.

The Geology of North Wales. 2nd Edition, 8vo (with many additions), pp. 623.

Ramsay was also joint author of the following :—

Sketch of the Structure of Parts of North and South Wales. (with W. T. Aveline). *Quarterly Journal Geological Society*, Vol. IV. (1848), pp. 294-299.

Geology of Parts of Wiltshire and Gloucestershire (with W. T. Aveline and E. Hull). *Memoirs Geological Survey*, 1858, pp. 1-16.

Report on Ice as an Agent of Geological Change (with O. Torell and H. Bauerman). *Geological Magazine*, Vol. VII. (1870), pp. 175-178.

On the Geology of Gibraltar (with J. Geikie). *Quarterly Journal Geological Society*, Vol. XXXIV., pp. 505-541.

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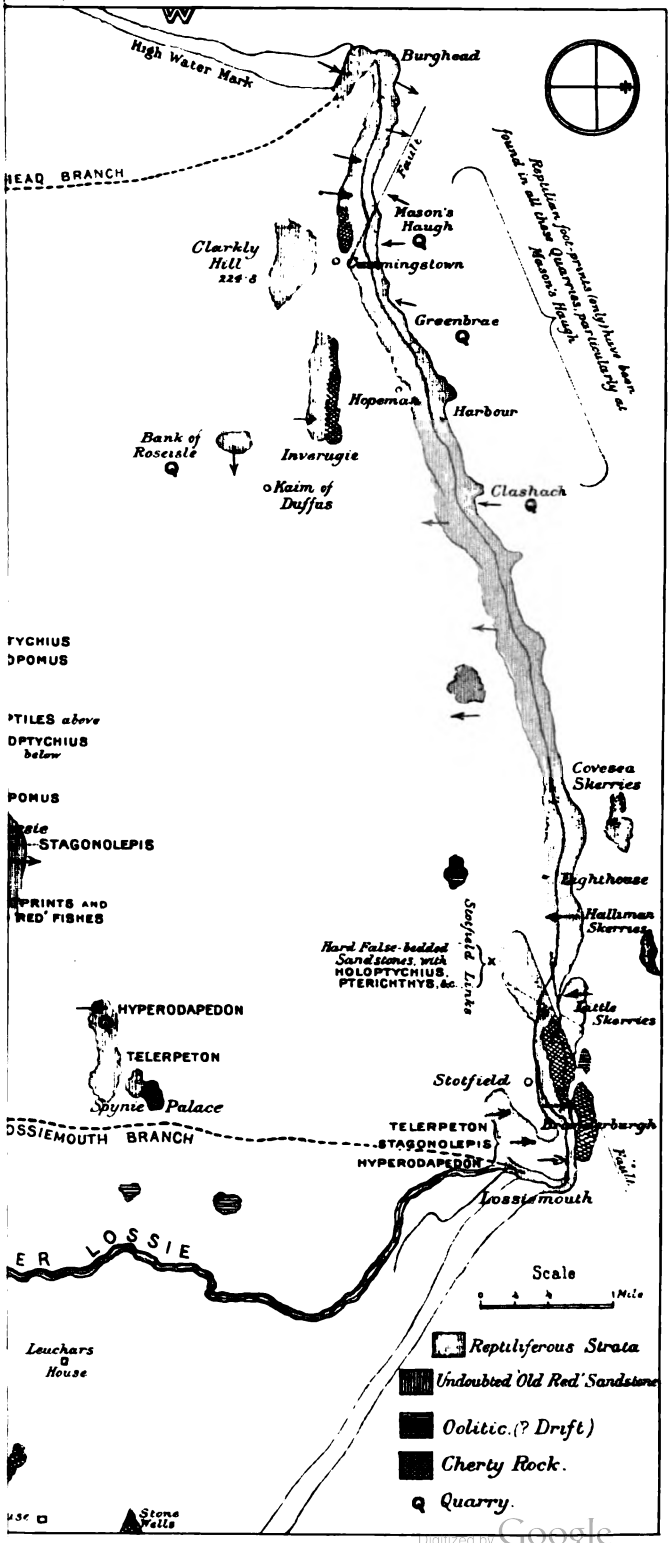

KETCH IN THE *IAIGH* OF MORAY (J.M.)

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XXVIII.—*The Reptiliferous Sandstones of Elgin (with Map).*

By the Rev. GEO. GORDON, LL.D., &c., of Birnie.

(Read 18th February 1892.)

EVER since the discovery of the *Telerpeton Elginense*, about forty years ago, there has been a doubt as to its geologic age. When M. Agassiz saw the "drawing" of a very small portion of the scutes of the next discovered Elgin reptile he named it *Stagonolepis*, under the impression that it was a fish of Devonian age. It was some time after this, and from a flag, now in the Elgin Museum, that *Stagonolepis Robertsoni* was proved to be a reptile of high organisation and of no ordinary size. (Memoirs of the Geological Survey, Monograph III., 1877. Huxley.)

It was only when Professor Huxley gave in his report on the next, or third, discovery — the *Hyperodapedon Gordoni* (see *Quarterly Journal of the Geological Society* for 1859, 1869, and 1887), that Sir R. Murchison began to advocate a *Triassic* in place of a Devonian age for these reptiles. Some time prior to this change of view, so clear was Sir Roderick as to their "Old Red" age that he said, "Let proud Palæontology bow to field Stratigraphy;" while Professor Huxley wrote to the same correspondent, "Let the battle go as it may, I'll stick to my reptiles!"

This much to show what a keen interest was taken at the time in this question among geologists. The locality became celebrated, and drew many "Knights of the Hammer" to examine it, among whom may be mentioned Sir R. Murchison, Sir C. Lyell, Sir A. Ramsay, Sir W. Jardine, Sir A. Geikie, Professors Nicol of Aberdeen, Harkness, Judd, and Page. The Rev. W. Symonds declared that he would lose faith in geology if these reptiles should turn out to be of "Old Red" age. Another gentleman with considerable difficulty admitted the sheer possibility of their being so low in the crust of the earth.

A *Dicynodon*, and a nondescript animal (reptilian?) now in Edinburgh, may be added as Elgin discoveries, together with a new reptile from Spynie, lately sent to the British Museum, but not yet described. Moreover there are eight or ten blocks, of some promise, containing reptilian remains just sent from the Elgin Museum, to be examined and reported on by E. T. Newton, Esq.

Had none of these reptilian remains been found, the Elgin Sandstones would have been held on all hands to have been the uppermost or closing beds of the Devonian era. As laid down in Sir R. Murchison's early and pithy expression, above written,

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we can come to the true order in which animals or plants appeared and lived on the face of the earth, only when we read aright the sequence in which the strata or rocks that contain them were deposited.

A priori, or as a foregone conclusion, not a few, when they heard of these reptiles, said that they must be of Triassic age, as nothing of their order had ever been found lower down in the scale; but one great and leading difficulty, that presents itself strongly to the geological visitor of this district, is the total absence of any band or line of demarcation between the Holoptychian and Reptilian beds—such a band or break as would have naturally been expected to record itself in the lengthened interregnum that ran between the Devonian and the Trias, during which the Permian and the Carboniferous ages were passing by. There is, besides, no symptom of denudation having taken place while these fossiliferous beds were being deposited, so that it is only by actually seeing the fossil *in situ* that one can say whether it belongs to the supposed *Old Red* or the supposed *New Red;* neither is there any attending change in the dip, colour, or consistence of the beds, at the supposed point of contact, to distinguish the one set from the other. The inference seems to present itself that either the fish (Holoptychius and Glyptopomus) continued to flourish down to Triassic times, or that the reptiles appeared in Devonian strata. The latter I hold to be the more correct reading of this local page in the Book of Nature.

There was a bed of conglomerate in Cuttie's Hillock quarry, which was thought to separate the fish-bearing strata from those yielding the reptiles. This conglomerate has now been proved, by the extension of the quarry, to be of little extent. It is very unlike outside conglomerates, being composed, in its matrix, of white sandstone, and having as its contents small white quartz pebbles. There is, moreover, in the Elgin Museum, a portion of this conglomerate containing reptilian remains, showing that it must have been deposited near their times.

Although close to each other, as in Cuttie's Hillock quarry, reptilian remains have not, as yet, been found underneath, or mixed up with, those of "Old Red" fish. The Elgin Sandstones, particularly those now forming the ridge of Quarrywood, were once, most likely, in a condition similar to that in which we now know the sands of Culbin and its dunes to be. On these dunes the active *Lacerta* has been seen running about in the sunshine, and leaving its tiny "footprints in the sands of time," while recent Batrachians were croaking in the adjoining marshes, and the haddock and the flounder were swimming in the bordering firth. Upwards of thirty years ago, while viewing

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this far-spreading wilderness of pure sand, and believing that the agencies now at work would, in the future, act as they have done in the past, Sir Charles Lyell exclaimed, "What a manufactory *of* SANDSTONE!" In several places of the upper sandstones now under notice, there is a false bedding suggestive of wind as well as water being a factor in their arrangement.

The upper beds of the Spynie quarry have yielded specimens of most of the reptiles that have been discovered. These beds lie at the top of the Sandstone system, and immediately under the cherty or "limestone" rock, which is to be seen *in situ* close by, at the Bishop's Palace. In this quarry, as yet, no "Old Red" fish have appeared.

A mile or so westward, and in the Bishopmill quarry, Holoptychian scales have been got, and also a slab, now in the Elgin Museum, bearing footprints. At the top of the beds in this quarry, perfectly conformable, and under the well developed boulder clay, there is a stratum of whitish sandstone, which looks like the continuation of the Findrassie beds that lie about half a mile due north, and which contained some of the finest bits of *Stagonolepis* yet discovered. On the southern side of this quarry, and close by the public road, a bent and partially broken set of beds may be seen, in consistence like to the one under the boulder clay, probably part of a fold or of a fault running westwards to the Knock of Alves.

In the Lossiemouth escarpment, where so many good reptilian specimens have been found, the white sandstone beds may be traced down, conformably, to a red clayey stratum, at the back of Rockhouse, and very much resembling that of Scaatcraig. It probably contains fossils that would throw light on the question at issue, for, if it were projected westwards, it would meet a hard rock of a like colour, near the west end of the golfing ground, in which Mr Linn, of the Geological Survey, detected "Old Red" fish scales, of which there is a specimen in the Elgin Museum. (See map of Elgin by the Geological Survey.)

At the Nairn quarries there are many remains of "Old Red" fish. From these quarries there is a block of whitish sandstone, now in the Elgin Museum, which shows numerous marks, apparently reptilian footprints.

Between the Palæozoic rocks of Geanies in Ross-shire, and the Ichnites of Tarbatness, there lies one of the finest geological sections in the north of Scotland. In it no undoubted line of demarcation has been detected, such, at least, as would show the break which might be looked for between two formations so widely sundered in time as Trias and Devonian. It has, indeed, been suggested that these Tarbatness footprints may have been

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made at a very different geologic period, and by a totally different class of animals from those associated with the footprints seen on the opposite, or southern, shore of the Moray Firth. But, so like was the Ross-shire shore here to that at Lossiemouth and Cummingston, that the writer urged two resident geological friends to look out for these footprints, and they were by-and-by found!

The map of this district of Moray, lately published under the auspices of the Geological Survey, represents among its strata two distinct beds or deposits of "limestone," or Cherty rock, in age so far asunder as that one is placed in the "Old Red" and the other in a supposed Trias. It is suggested, with all deference, that the indication of one such deposit, and it at the top of the system, would sufficiently meet all the circumstances of the case. This peculiar rock is a concretionary sandstone rather than a pure limestone. Sir Charles Lyell said of it, as it shows itself at Lossiemouth, that he had never met with its like. It is to be seen, in more or less extent, at Lossiemouth, Bishop's Palace of Spynie, and at Linksfield, while Elgin is built over it. It has been burned, for agricultural and other purposes, at Stonewells, Waulkmill, Glassgreen, New Elgin, Bilboahall, Palmercross, and Inverugie. It is well seen at Cothall, on the Findhorn. True it is that at Sheriffmill, near Elgin, where there once were lime-kilns, it lies at the southern foot of the the high Quarrywood ridge, but it is considered to have been brought down by a fault or by a fold. An evidence of this may be traced in the bending of some of the beds at Bishopmill, and in a somewhat fractured line that runs directly west to the Knock of Alves, and also in the *southern* dip of the limestone at Linksfield.

Sir R. Murchison, who was well acquainted with this part of Scotland, considered that this superior deposit, as an overlying shield, had, in glacial times, been the saving of the fertile flat of Moray. It had presented its tough shoulders to the icy forces that then came upon it, at least in their last raspings, from the north-north-west.

Had there been two beds of this "limestone," as represented in the map above alluded to, it is remarkable that only one appears in the Findhorn section, where the Elgin beds are otherwise so well and fully exhibited. It is likewise noteworthy that there is no vestige of them to be seen at or around Cuttie's Hillock, or the other localities where both sets of fossils nearly meet. In support of the idea that there is but one deposit of limestone, or "Cherty rock," in the district, it may be stated that galena—not a very common mineral—is found profusely in the limestone at Lossiemouth, which is mapped as Trias; and

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that this mineral is also found, though sparingly, in the limestone at Sheriffmill, which was most likely considered of Devonian age. "Salmons in both," some may quote!

This map (at least two copies of it purchased from the Edinburgh publishers) is so indistinct in its colourings and tracings of the two presumed formations that, without descriptive letterpress and sections, it is difficult to be read even by those well acquainted with the ground.

It is more with the view of reminding geologists that the period of the introduction of these reptiles is still a *questio vexata*, and to invite further inquiry, than with the prospect of directly settling it, that this paper has been put forward.

There is no "bone-bed," or leading stratum, where these remains are met with. Both sorts of fossils—fish and reptile—are sparsely scattered, and often fragmentary. If any excavation were to be made for fossils alone, in order to get more light on the subject, it should be, in the first place, in the Lossiemouth quarries, and in the platform left by the quarrymen. They did not go farther down, because the bed was softish and rubbly, but it was at this horizon more than elsewhere in the quarry that most fossils were found.

The quarrymen have really been the discoverers of these most interesting reptilian remains. They are intelligent and observant, and not likely to throw anything worth preserving into the rubbish-heap.

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XXIX.—*Notes on the Flood which occurred in the River Tweed and its Tributaries on 21st September* 1891: *with Observations on the Terraces of the River Tweed and other Scottish Rivers.* By RALPH RICHARDSON, F.R.S.E.

(18th February 1892.)

(ABSTRACT.)

AMONG the greatest floods which have occurred in the River Tweed in recent times are those of 10th May 1796 (causing a rise of 12½ feet at Old Melrose and 14 feet at Kelso), 20th October 1797, and 6th September 1807.[1] Our late President, Mr Milne Home (who lived on Tweedside) said that the most remarkable flood he ever knew to have occurred in the Tweed was on 9th February 1831, when the river rose as much as 23 feet (at Milnegraden, &c.), above its normal summer height.[2] There was also a great flood in the Tweed on 9th March 1881.

On 21st September 1891 the Tweed rose 11 feet above its normal level at Melrose Bridge (opposite The Pavilion), as shown on the flood-gauge on the Bridge. On Sunday, 20th September 1891, heavy rain fell all day and night, and next day the rain continued, accompanied by a violent storm of wind from the north-east. Fields and meadows on both banks of the river were flooded, and the Tweed acquired the dimensions, strength, and appearance of an arm of the sea with a strong tide running.

The Gala, Leader, Leithen, and other tributaries of the Tweed, were in greater flood on 21st September 1891 than had been known for many years. Railway bridges were broken and fields flooded and devastated all down the valley of Gala Water. For weeks subsequently this valley exhibited scenes of disorder. Ploughed fields were covered beneath a mass of gravel, walls were carried away, stooks of corn were hanging among hedgerows. Galashiels was inundated, and gardens swept away. The river flowed over stone bridges, destroyed mill lades, and invaded shops and dwellings. Railway traffic was stopped for weeks.

The following returns will show how heavy the rainfall was on 20th and 21st September 1891 :—

[1] Russell's "Haigs of Bemersyde," p. 482. Kelso Bridge was swept away in 1797.

[2] Trans. Royal Society of Edin., vol. xxvii., p. 515.

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	20th Sept. Inches.	21st Sept. Inches.
Near head of Gala Water, Middleton	3·35	·59
Gala Water, Galashiels	1.49	·43
River Tweed, Melrose	·60	1·00
River Tweed, Kelso	1·09	1·02
River Tweed, Marchmont	2·04	1·89
Rule Water, Wolflee	2·29	1·92

Mr Richardson then referred to the terraces fringing the River Tweed, pointing out that they are, at least, three in number—viz. (1) a comparatively recent terrace, (2) an older, and (3) a still older terrace. Examples of all three may be seen at Gattonside House, near Melrose. The *first* terrace, or Haughland of Gattonside, is situated about 20 feet above the normal level of the River Tweed; whilst the mansion-house of Gattonside occupies the second terrace, which is composed of a compact mass of waterworn pebbles. This *second* terrace is situated 50 feet above the level at which the Tweed presently flows. The *third* terrace, that on which part of Gattonside village stands, is no less then 175 feet above the present level of the Tweed. Mr Richardson computed these heights by aneroid.

From the evidence of these terraces, we perceive that the Tweed has gradually sunk in level and eroded its valley 175 feet, the height of the highest terrace, until it attained its present level.

With these terraces of the Tweed, Mr Richardson compared the terraces of the Tay and its tributaries, upon which he had read a paper before the Society in 1884.[1] He had found at Pitlochry *seven* well marked terraces rising respectively 10 feet, 40 feet, 60 feet, 80 feet, 90 feet, 110 feet, and 130 feet above the River Tummel.

Mr Richardson referred to Mr Milne Home's elaborate "Notice of High-Water Marks on the Banks of the River Tweed and some of its Tributaries," which is printed in the 27th volume of the Transactions of the Royal Society of Edinburgh, being a paper read in 1875.[2] Mr Milne Home thought that "if the existence of old sea-margins up to even the smallest heights above the present level of the *sea* be admitted, then all the rivers *must necessarily have had their channels that much higher than now;* in which case, flood-marks must have been made on their banks at heights suited to the higher channels so occupied by them."

[1] Trans. Edin. Geol. Society, vol. v., p. 56.
[2] *Op. Cit. Supra*, p. 561.

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Mr Richardson preferred to think that it was the land, and not the sea, that rose. A flood-mark being necessarily the work of a rapid and temporary agent, whereas the formation of these terraces demanded a prolonged period and continuous agent, he thought that River terraces were not the result of floods, but may have been formed whilst the land was rising. Each terrace, in his opinion, represents the ancient alluvial meadow which bordered the river during a lengthened period of tranquillity. That period would be interrupted by a movement of elevation which, by raising the river-bed, would cause the river to flow with increased velocity and erosion. The river would cut its way through its old alluvial flat, which is now found in a fragmentary state as a terrace. When, by a sufficient fall in the level of its bed, the river again arrived at a period of tranquillity, it would again produce an alluvial meadow; and this again is shown to us in a fragmentary form as a terrace, as elevation of the river-bed again occurred. The formation of a river flat, such as Mr Richardson believed River terraces to be, demanded a prolonged period during which the river flowed placidly (not in a flood or spate) in a series of gently winding curves, which led to the gradual production and extension of the alluvial flat.

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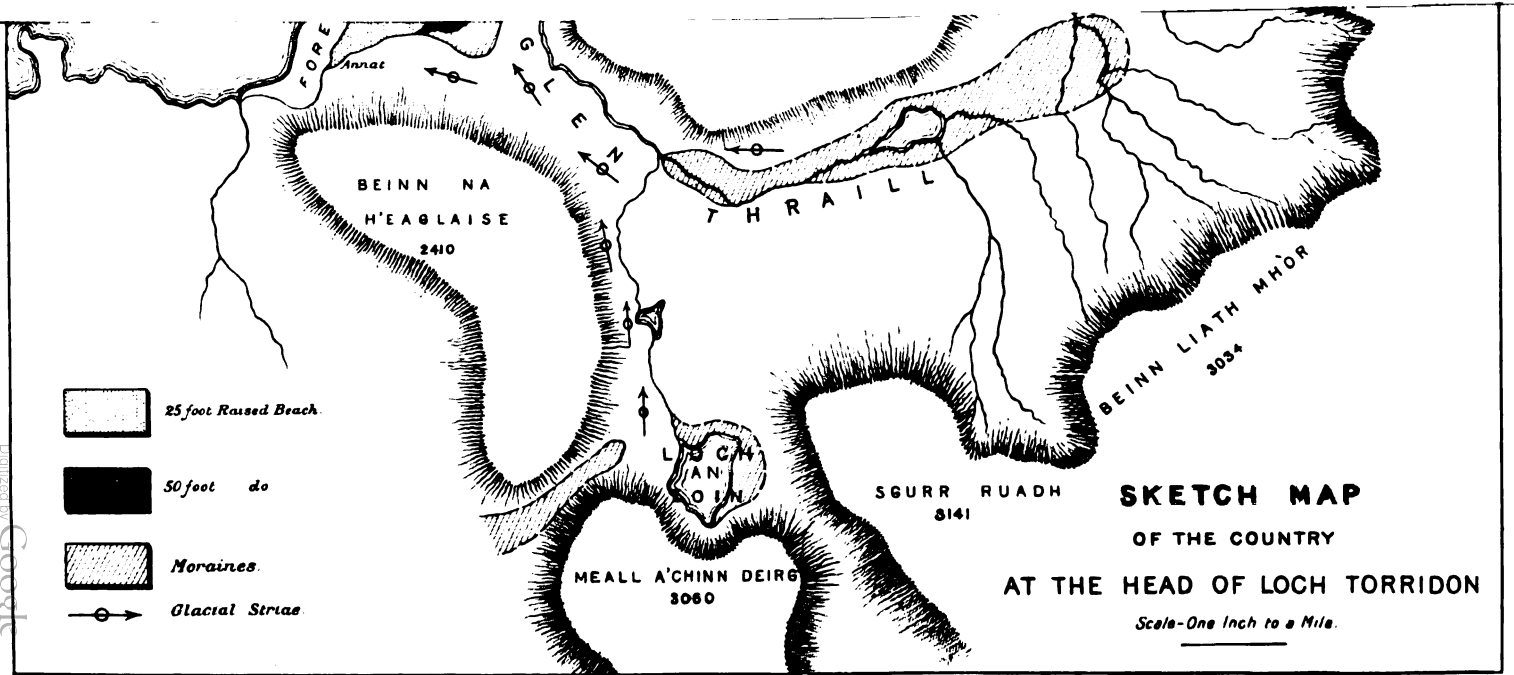

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XXX.—*On the Occurrence of Moraines later than the 50-foot Beach in the North-West Highlands.* By LIONEL W. HINXMAN, B.A., of H.M. Geological Survey of Scotland.

(*Communicated by permission of the Director-General of the Geological Survey.*)

(Read 21st April 1892.)

ROUND the head of Loch Torridon, an arm of the sea which penetrates for more than ten miles into the mountains of West Ross, are grouped the bare and rugged peaks of the Torridon, Coulin, and Ben Damph forests, most of which reach or exceed a height of 3000 feet above sea-level, Leagach, the highest, rising 3400 feet directly from the water's edge.

These ranges may be described as forming roughly a triangle, of which the head of the loch is the apex, Leagach and Beinn na h' Eaglaise are respectively the northern and southern sides, while the base is represented by the western front of the hills known collectively as the "Grey Heads," and individually as Sgurr Dubh, Beinn Liath Mhór, Sgurr Ruadh, and Meall a' Chinn Deirg. They are composed for the most part of red and purple grits and sandstones, lately proved to be of pre-Cambrian age, and to which the name of Torridonian has been given, from this region, in which they are most characteristically developed. Outliers of Cambrian Quartzite also occur, either capping the highest peaks, or in lenticular and wedge-shaped masses repeated by thrusts at various horizons in the Torridonian.

This triangular area is intersected by two main valleys—Glen Torridon and the valley of the Amhainn Thraill—which converge at a point three-quarters of a mile from the head of the loch. Glen Torridon is straight, narrow, and trench-like, with rocky precipitous sides, and—except at the head—no tributary glens. Glen Thraill is wider, especially in the upper part, where it bifurcates, the northern branch running up to the foot of Beinn Liath Mhór, and only separated by a low drift and moraine-covered *col* from the head-waters of the Torridon river. The southern branch is bare and rocky, and descends steeply from the great corrie at the foot of Meall a' Chinn Deirg, in which lies Loch an Eoin. This corrie may be regarded as the probable gathering-ground of the glacier whose moraines are here under consideration.

At the head of Loch Torridon the 25 and 50 feet raised beaches form a plateau of considerable extent, the latter extending for more than a mile up Glen Torridon as a narrow fringe

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to the rocky sides of the valley. Just below the confluence of the Torridon and Thraill rivers, a fan of well-formed moraines, pouring out of Glen Thraill, streams down upon the flat surface of the 50 feet beach, and at the side of the road leading to Annat, and immediately to the south of the bridge, an opening made for road-metal in the face of one of these moraines gives a clear section of the moraine and underlying terrace of marine alluvium. The section shows six feet of loose earthy moraine-stuff, filled with large angular blocks of Torridon sandstone, together with a few smaller fragments of Cambrian quartzite, all derived from, and agreeing in lithological character with, the rocks of the catchment-basin. This moraine-stuff rests immediately upon the raised beach deposits, which consist of alternating layers of horizontally-bedded sand and rolled shingle.

Nor is the superposition of the moraines upon the raised beach the only evidence of their later origin. An examination of the pebbles that compose these beaches shows that a large proportion—sometimes as much as 60 per cent.—consists of fragments of quartz-schist and flaggy gneiss, derived from the rocks known by the Survey as the "Eastern Schists."

These rocks do not occur *in situ* within the watershed of the streams flowing into Loch Torridon, the nearest point where they are found being on the east side of the Coulin Glen.

It is therefore evident that the raised beaches must have been formed from the detritus brought down by the streams at a time when the valleys through which they flowed were more or less filled with boulder clay and morainic deposits of earlier date than those with which we are now dealing. Traces of this older drift are still to be found over the cols and on the hill-sides at the heads of the valleys; but the bottoms of the glens have been swept completely bare by the latest phase of the valley-glaciers, so that in the lower part of Glen Thraill the moraines rest directly upon the smoothed and striated rock-floor, and a fragment of the "Eastern Schists," derived from the earlier drift, is hard to find.

Professor Geikie has shown that the genial period which followed the close of the great ice-age was succeeded by a recrudescence of colder conditions, during which the great forests that covered the country perished, and were overwhelmed in the peat mosses in which their remains are now found.[1] And that there were further oscillations of climate is evident from the alternations of peat and forest growth seen in the deeper mosses.

It therefore seems probable that, after the appearance of

[1] "Prehistoric Europe," chap. xvii.

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Neolithic Man in Scotland, the glens and corries of West Ross were again occupied by local glaciers that descended to sea-level, and left those striae and moraines whose wonderfully fresh appearance has always made it difficult to believe that their origin must be referred back to the remote ages of the Glacial Period.

Nor do we need to invoke any great change of climate to produce the conditions necessary for the existence of these glaciers. Round Loch Torridon, as on many other sea lochs of the West Coast, the mountains rise directly from the shore to heights of upwards of 3000 feet. The snow-line under present conditions would be found in this latitude at a height not greater than 5500 feet above the sea, and a very slight lowering of the mean annual temperature, in this region of great precipitation, would be sufficient to produce permanent snowfields on the mountain tops, with glaciers in the valleys descending to the sea.*

We are thus led to the conclusion that the terminal moraines of the Glen Thraill glacier were laid down subsequently to, and probably at a considerable interval after, the formation of the 50 feet beach on this part of the West Coast of Scotland.

At the head of Loch Erribol, in North Sutherland, as has been pointed out by Sir Archibald Geikie,† and as my friends and colleagues, Messrs Peach and Horne, have shown by detailed mapping, similar phenomena occur, though in that locality satisfactory sections, such as those described above, are wanting.

Nor are these isolated instances. In various parts of the Continent "post-glacial moraines" have lately been described, as by Dr Penck in the Pyrenees, Dr Kerner in the valley of the Stubai near Innsbruck, and by Dr Brückner in the Salzach region.

* A fall of 7° or 8° in the mean annual temperature would bring the line of perpetual snow below the tops of the mountains of West Ross-shire, but an additional diminution of at least 4° would probably be necessary to produce glaciers descending to sea-level.

† "Scenery of Scotland," 2nd ed., 1887, p. 272.

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XXXI.—*Note on Homosteus Milleri and its Distribution in the Old Red Sandstone of the North of Scotland.*

(Read 21st April 1892.)

THE fish now known as *Homosteus Milleri* (*Traq.*) was formerly the celebrated *Asterolepis* of the "Footprints of the Creator." The now renowned specimens of this most interesting fish, the interpretation of the remains of which was a matter of great difficulty until recently, are exhibited in the Museum of Science and Art, Edinburgh, and it is needless to say that they are the identical specimens which Dick with much toil wrested from their adamantine surroundings in the Low Old Red Flagstones of Caithness. These specimens he handed over to Hugh Miller, and it was on them and also on the remains of other species found here that the superstructure of much of the "Footprints of the Creator" was built.

Subsequent research has shown that some of the specimens identified by H. Miller, and figured as teeth and scales of *Asterolepis*, do not really belong to that fish, but are teeth and scales of what is now known as *Glyptolepis*. Nevertheless, the figure of the dorsal and ventral sides of the cranial buckler are well represented, and are still of great use.

Lately Dr R. H. Traquair has shown that the fish which was originally identified as belonging to the genus *Asterolepis* was not really referable to that genus, but belonged to the genus *Homosteus* of Asmuss. Therefore the old and familiar, one might almost call it, the classical name of *Asterolepis*, so far as the fish of the "Footprints" is concerned, drops out of view.

After Dick's death there seems to have been quite a stagnation in the search for new forms in the flagstones of Caithness. One of the unfortunate things in connection with the specimens of *Homosteus* which he left behind him is that no record is preserved of the locality or horizon from which they came. The scrutiny of the specimens, however, revealed this fact that some at least came from the sea-shore, and a passage in the "Cruise of the Betsy" indicates that it was some spot between Thurso and Murkle. To show how rare this fish was in the past I need only say that the British Museum has not yet to my knowledge one complete specimen. It will be my duty, however, to show soon that fragments at least are tolerably common now.

On becoming settled at Thurso, I set myself to find out what additional information might be gleaned by a little field-work either in the direction of finding out additional details as to the structure of certain parts of the fish which are not yet known, or

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in tracing the fish through the various beds upwards. *Homosteus* being a coccostean in structure, it was reasonable to expect that some specimen might turn up showing the vertebral column, but so far the search has been fruitless. I have been able, however, to ascertain that it is by no means uncommon, so far as fragments of it are concerned, but that specimens of the head, which is the only part yet known, are as rare as ever.

It seems to occur in the light-blue flag which is used for fencing and other purposes. A few bones and part of a head are exposed on the beach opposite Thurso East Castle. In a little bay on the shore near Murkle there is a bed of limestone in a fragment of which, on the beach, I noticed some parts of this fish. The district round about Forss has a few quarries which have yielded a few specimens. At Thusator, two miles from this spot, I have seen parts of a bone an inch thick, and I have obtained a specimen from Toldale Quarry, a short distance from here. On the farm of a friend of mine here, there is in one of his flag fences a very fine specimen of the trapezoidal median occipital plate, but it is getting rather weathered now. The head of the fish it belonged to must have been two feet long. I have also noticed fragments of what appears to be *Homosteus* bones in the bed of a stream on the hill pasture of the farm of Scrabster. Not long ago, I heard of the big bone of some fossil fish being used as fuel for a fire, a fact perfectly credible, seeing that pieces of the soft beds in which *Osteolepis* occurs, will burn with a bright flame for one or two minutes after being put into a hot fire. This fish could only have been a *Homosteus*. Hugh Miller found a bone with a curious nail-like process which we now know to be the median dorsal plate of *Homosteus* in the Old Red Beds of Stromness, thereby showing that the fish occurred at the very base of the system. The localities I have given show that it ranges to almost the top of the Lower Old Red.

The specimen exhibited to the Society was obtained in rather a curious manner. I happened to meet a young man on the road here, and the conversation turning on the representation of a fossil fish, which somebody of an idle and artistic frame of mind had represented in black paint on a flagstone skirting the highway, he chanced to mention that there was a bone covering nearly a whole flagstone in a field not far off. Knowing this could only be a *Homosteus*, I hurried thither that very evening, and was astonished and delighted to find it to be one of the largest and completest specimens of the ventral aspect of *Homosteus* that had ever been found. It shows especially well the anterior part of the head, but a portion of the right orbit, and the bones forming it, is still under the matrix.

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XXXII.—*On Building Stones used in Edinburgh: their Geological Sources, Relative Durability, and other Characteristics.*

By GEORGE CRAIG, Architect.

(Read 5th May 1892.)

EDINBURGH has long been advantageously situated in regard to good building stones, and her grey stone buildings—the just pride of her citizens—have caused the poet to name her the "Grey Metropolis of the North."

The oldest known freestone quarries are those of Craigleith, Craigmillar, Salisbury Crags, Lochend, Bruntsfield, Ravelston, and Quarryholes.

Among these, Craigleith long occupied the chief place, and for a long series of years the public and private buildings of the New Town were almost entirely built with stone from this famous quarry. Afterwards Redhall, Binny, and others, were opened up, and although somewhat behind the quality of Craigleith, are still very good building stones. About the year 1860, Polmaise and Plean came to be extensively used.

Gradually the stones quarried in the district have become practically wrought out, or can only be obtained at a high price, and of late years we have had to go further afield, and bring stones from long distances, as far even as from England. This is to be regretted, while we understand that there is still plenty of good sandstone to the west of the city that could be quarried without much difficulty.

Within the last ten years the pink stone of the New Red formation (some of which is now recognised as Triassic) has come into favour, and has been used in several of our public buildings.

While the older stones have been well proved, and the chisel marks of the early masons are still distinct, as seen, for example, on the Craigleith faces, the lately introduced stones are not yet thoroughly proved, and several are already showing signs of weathering within the short time of their exposure.

In order to obtain as much reliable information as to the destination of many of our building stones after leaving the quarry, I put myself into communication with quarry owners, surveyors, inspectors and contractors at different places, and met with a kind response from many, and I take this opportunity of returning them my warmest thanks for the information afforded, especially to Professor T. H. Beare, of University College, London, who kindly supplied many of the tests, several of which are from the "Institute of Civil Engineers' Proceedings."

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An investigation such as I have attempted is a work of no small difficulty, as very few records have been kept of the ultimate destination of most of the older building stones, and even now much trouble is entailed in finding out the quarries from which many of the modern buildings have been obtained. Such results as I have arrived at, however, although necessarily imperfect, will, I hope, prove useful as a first contribution to a branch of practical local geology that has been but little investigated, although full of both economic and scientific interest.

The chief British building stones are classed under the heads of granites, flagstones, limestones, dolomites, and sandstones, but our present paper will deal almost wholly with the last class, as this is almost exclusively used in the Edinburgh district.

Composition of Sandstone.—Sandstones are generally composed of grains of quartz, cemented together by silica, carbonate of magnesia, carbonate of lime, oxide of iron, or by mixtures of these substances. In addition, there are often other substances, such as mica, fragments of limestone, argillaceous and carbonaceous matter, interspersed throughout the mass.

The grains of quartz being imperishable, the weathering qualities of the rock depend upon the nature of the cementing substances, and on their powers of resistance to atmospheric action.

When the grains are of carbonate of lime embedded in a silicious cement, the grains are the first to give way under the influence of the weather. They appear in all colours—white, black, grey, greenish grey, red, brown, fawn coloured, and yellow —and these colours sometimes fade, and sometimes become intensified by exposure to the weather.

In dealing with the various stones, the well-known fact must be borne in mind that the qualities and chemical composition of the stones from the same quarry vary very much; and, again, stones that may withstand the atmosphere well in the country may not do so in the trying, smoky atmosphere of the city.

In selecting sandstones, the finer grained, the more homogeneous in texture, the least absorbent of water, and the freest from lime and iron, should be preferred. All blocks containing grains or nodules of sulphide of iron should be carefully rejected, as in a few years such nodules oxidise and become blackish brown, unsightly stains, which finally weather out into cavities and destroy the strength and body of the stone.

Craigleith Quarry.

This quarry has an area of about seven acres and is about 200 feet deep; the zig-zag road to the bottom is three-quarters of a mile in length. It is not known when the quarry was opened,

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but it was worked as early as the commencement of the seventeenth century. In its early years it was rented for £50 per annum, but between 1820 to 1826 it yielded about £5,510 per annum.

The Craigleith rock was long the principal stone used in the public and private buildings in the city. Immense blocks could be obtained which were susceptible of great delicacy of sculpture, and formed one of the most durable sandstones in the United Kingdom.

"In 1823, there was excavated a stone of such dimensions and weight," says the *Edinburgh Weekly Journal* for November of that year, "as to be without parallel in ancient or modern times. In length it was upwards of 136 feet, averaging 20 feet in breadth, and its computed weight was 1500 tons. It was longitudinal, cut from a stratum of very fine rock. The greater part of it was conveyed to the Calton Hill, where it now forms the architrave of the National Monument, and the rest was sent by sea to Buckingham Palace."

Several large fossil coniferous trees have been found in the rock, and they have been described in the earlier volumes of the Transactions of the Royal Society of Edinburgh, where illustrations of the quarry are to be found.

As a proof of its extraordinary resistance to the effects of the weather and atmosphere, the tool marks on some of the old buildings can be plainly seen at the present day, proving the forcible remark of a Glasgow Professor, that the stone "is well-nigh imperishable."

Locality.—About a mile to the west of Edinburgh.

Geological Position.—In the middle portion of the Lower Carboniferous or calciferous sandstone series, below the base of the upper or oil-shale group.

Chemical Analysis.—It consists of quartz grains united by a silicious cement with small plates of mica—

Silica	98·3
Carbonate of lime	1·1
Iron and alumina	0·6

(*Report of Commissioners, New Houses of Parliament.*)

Density.—2·22.

Specific Gravity.—2·45.

Absorption of Water.—3·61.

Crushing Load.—861·9 tons per square foot. (Beare.)

Weight.—138·6 lbs. per cubic foot.

Tint.—Grey.

Texture.—Very hard and close.

Weathering.—All the buildings of Craigleith stone are practically unaltered by the weather, and the polished faces retain their original gloss and clear appearance.

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Buildings.—Among the numerous buildings erected are the Register House, 1776-1826; St Andrew's Church, George Street, 1785; Old University, 1789-1834; Leith High School, 1806; St George's Church, 1812; Leith Town Hall, 1827; Dean Bridge, 1832; and the whole of Charlotte Square.

It has been extensively used for engine seats, and column foundations where great strength is required, also for dock-works and piers.

There are no houses built entirely of it now, and it is used principally for steps, foundations, and rubble.

The lower rock is used for monuments, grindstones, and glass-cutting.

It is largely exported to London, United States, and other places.

Craigmillar Quarry.

Locality.—One of the old worked quarries in the district, about two miles south-east of Edinburgh.

Geological Position.—Among the red rocks at the lowest portion of the calciferous sandstone series.

Crushing Load.—982·0 tons per square foot. (Beare.)

Weight.—153·6 lbs. per cubic foot.

Tint.—Purplish white to cream colour.

Texture.—Hard, and full of pebbles.

Weathering.—Good.

Buildings.—Heriot Hospital, about the middle of the seventeenth century; Leith Docks, 1876.

Still being worked in a limited way for kerbing and such like scantling.

Ravelston Quarry.

Locality.—Ravelston, about one-and-a-half mile west of Edinburgh.

Geological Position.—The massive sandstones once very extensively quarried seem to occupy the same position as the Craigleith beds below the base of the oil-shale series.

Density.—2·26.

Absorption of Water.—2·93. (Beare.)

Crushing Load.—855·8 tons per square foot.

Weight.—141·1 lbs. per cubic foot. (Beare.)

Tint.—Greyish white.

Texture.—Fine grained.

Buildings,—Villas at Trinity.

It is not known when these quarries were opened, but they have been worked from a very early period. In the east the good rock is so deeply covered with "tirr" that it has been little worked for a long time, and very little at present.

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Ravelston Black Quarry.

Locality.—The old Black Quarry, a little further west, just re-opened.

Density.—2·23.

Absorption of Water.—3·25. (Beare.)

Crushing Load.—782·0 tons per square foot. (Beare.)

Weight.—139·2 lbs. per cubic foot. (Beare.)

Tint.—Dark grey.

Texture.—Fine and hard.

Granton Quarry.

Locality.—The three Granton quarries, situated about one mile to the west of Granton, Midlothian, are very extensive.

It is not known when they were first opened. In the City Treasurer's Accounts for 1552-3 we read of half an ell of velvet given to the Laird of "Carube (Carrubber ?) for licence to wyn stones on his lands of Granton to the schoir for the hale space of a year."

The stone was once very extensively used for building.

About fifty years ago, when the Duke of Buccleuch began to build Granton Harbour, a quarry was opened at Granton point to supply material for the undertaking. It gradually extended in area and depth until, in the course of twenty years, material had been excavated to a depth of nearly 80 feet over eight acres —only second in extent to the great quarry of Craigleith. The great fossil tree Araucaria, 75 feet long, and tapering from 5 to 2 feet in diameter, was found here.

In the autumn of 1855 a very fine stratum of sandstone at the west end had been followed, until the men became apprehensive of an inbreak of the sea, and refused to go further in that direction. The last week of October of that year was very stormy, when the water broke in and flooded the quarry. The manager and his family and engineer had a very narrow escape, as the greater part of his house fell into the abyss. The cause of the accident was never exactly ascertained. It is supposed that the sandstone where the break occurred rested on a bed of stiff clay, had become saturated and softened by the water, so as to form a slippery surface over which the rock slid in consequence of the pressure of a very high tide outside. The quarry plant was valued at several thousands of pounds, and during the summer of 1856 determined efforts were made to recover it by means of diving-bells. After a few months it was found that the cost of the work far exceeded the value of the material recovered, and so the quarry and the "quarry graith" were finally abandoned.

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For over thirty years the tide has ebbed and flowed in Granton Quarry. The other two quarries are also flooded.

Geological Position.—Granton Quarries are part of the white sandstone which occupy a large tract of country to the west of Edinburgh, and are apparently the northern prolongation of the Craigleith beds.

Tint.—Cream coloured.

Texture.—Hard.

Weathering.—Good.

Buildings.—The extensive Pier and Breakwater at Granton, 1835-8, are built out of them. The Watt Statue also came from it. A great many blocks in the rough state can still be seen piled up alongside the Breakwater and Harbour of Granton.

Redhall Quarry.

Locality.—A little above Slateford, Midlothian.

Geological Position.—The middle portion of the Lower Carboniferous series.

Crushing Load.—662 tons per square foot.

Weight.—143·8 lbs. per cubic foot.

Tint.—Of two tints, one of which is red, containing a large percentage of iron, and the other white, but which gets discoloured when exposed to the atmosphere.

Texture.—Softer than Craigleith, easier wrought, and consequently less expensive. When the demand for Craigleith diminished it was extensively worked, but is not now much in vogue.

Weathering.—The weathering qualities are good.

Buildings.—It is standing well at St Paul's Church, York Place, 1816-18; St John's Church, Princes Street, 1817, except a few stones which have been set on edge; Lothian Road U.P. Church, 1831; St Ninian's Free Church, Leith, 1839; Stables, Tod's Mills, Leith, 1859; Synod Hall, 1871, except a few mouldings below cornice; Fountainbridge School, 1874; Gorgie School, 1876.

Binny Quarry.

Locality.—Binny, near Uphall, Linlithgowshire.

Geological Position.—This celebrated bed of sandstone occupies a well-defined position in the oil-shale series, or upper part of the Lower Carboniferous formation of Linlithgowshire. Its exact position in that series was for long a matter of uncertainty, but Mr H. M. Cadell, who has for several years been engaged in working out the geology of the oil-shale districts, has ascertained definitely that the sandstone formerly so extensively

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quarried at Binny is part of the well-marked zone of sandstone that is known to lie below the Broxburn and above the Dunnet-shales, at a depth of about 1,600 feet below the carboniferous limestone. The position of the Broxburn shale has been well proved in various places from the shore of the Firth of Forth at Queensferry, south-westwards to Cobinshaw Loch—a distance as the crow flies of 18 miles—and hence to find the position of the sandstone below is a matter of no great difficulty. Many quarries, of which that at Binny is only one, have been opened in this bed of rock which varies in quality and thickness from place to place.

At Binny quarries, the sandstone lies in beds which form the crest of an anticline, and dip away to the east, west, and south. The Broxburn shale is mined a short distance east of the sandstone outcrop, and as there is a nearly continuous section exposed between the sandstone and the shale, there is now no doubt whatever as to the exact geological position of the Binny rock.

Density.—2·16.

Absorption of Water.—5·22. (Beare.)

Crushing Load.—569·1 tons per square foot.

Weight.—135·1 lbs. per cubic foot.

Tint.—Grey.

Texture.—First-class and close.

Weathering.—The buildings undernoted show practically no sign of weathering.

Buildings.—The stone was once extensively used for building, but now little used except for monumental purposes.

Among the buildings erected are Bank of Scotland (first), 1806; The Scott-Monument, 1840-6; Donaldson's Hospital, 1842-51; National Gallery, 1850-9; Post Office, 1866; Register House, ; Assembly Hall and Spire, 1842-4; The Queen's Statue at the Royal Institute, about 1836, which weighed about 20 tons when it left the quarry.

Hailes Quarry.

Locality.—About 4 miles west of Edinburgh.

Geological Position.—In the middle portion of the Lower Carboniferous.

It has been quarried to a depth of over 100 feet. Large quantities are now being exported to London.

The beds are remarkable for the regularity of the laminæ. Their laminated character is due to the large quantity of mica which they contain.

Density.—2·30 for the white rock; 2·29 for the blue.

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Absorption of Water.—3·71 for white, and 4·70 for blue Hailes.

Crushing Load.—White Hailes 662· tons per square foot, and blue Hailes 459·7 tons.

Weight.—White Hailes 143·8 lbs. per cubic foot, and blue Hailes 143·2 lbs. (Beare.)

Tint.—The lower beds are of a dark grey tint, the upper red and ferruginous, another bed is of a blue tint.

Texture.—Hard and close-grained, except in the clayey beds.

Weathering.—Many buildings are standing well, but some of the stones are weathering badly on account of the thick clay bands, especially of the blue and grey rock.

Buildings. — Examples of the grey stone can be seen at Dalry School, 1876; Lochend Road School, 1886; Sciennes School, 1891.

The blue stone at Plewlands Villa, 1878.

The red stone at Red House, Cluny Gardens, 1880, and many others.

Hailes stone is a capital stone for foundations, and where great strength is required. It is very extensively used for rubble work.

Polmaise Quarry.

Locality.—Polmaise, Bannockburn, Stirlingshire.

Geological Position.—In the Carboniferous limestone series.

Density.—2·27.

Absorption of Water.—4·58.

Crushing Load.—551·5 tons per quare foot.

Weight.—141·7 lbs. per cubic foot. (Beare.)

Tint.—White, also cream colour.

Texture.—Very fine.

Weathering. — This stone appears to be uncertain in its weathering capabilities.

Buildings.—It is weathering badly at Nos. 42 and 43 Drumsheugh Gardens, 1877; standing well at the Conservative Club, 1883; but some stones show signs of weathering at the New Medical School; and is weathering badly at Morningside U.P. Church, 1884; at M'Dowell's shop George Street, the moulded blocks of the cornice weathered away in about 10 years; also weathering badly at Wholesale Co-operative Society, Leith Links, 1885; shows signs at the Pillars in Meadows, 1888; and is unsatisfactory at M'Ewan Hall, 1889.

The good rock has been practically worked out, and the quarry is now closed.

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Dalmeny Quarry.

Locality.—Dalmeny, Midlothian.

Geological Position.—In the upper portion of the Lower Carboniferous or oil-shale series. The sandstone quarried formerly here is a part of the zone of sandstones below the Broxburn shale which is worked here in the pit of the Dalmeny Oil Company, a short distance west of the old quarry.

Tint.—Light grey.

Texture.—Closely resembles Binny.

Buildings.—At Palace Hotel, it is weathering well, and the Union Bank, George Street, 1874, except a few stones show slight signs of decay beneath cornices. East side of Palmerston Place and Coates Gardens are built out of it.

At the Windsor Hotel, 1875-80, the stones are decaying beneath the cornices; at 9-11 East Hermitage Place, Leith Links, 1883, it is weathering well. Tenements 69 and 71 Great Junction Street, 1884, with stone from new quarry is decaying at cornice projections. At Pillars in the Meadows, 1888, it is weathering badly. Extensively used at Drumsheugh, Magdala Crescent, and neighbouring streets.

It was once extensively used, but now practically worked out.

Plean Quarry.

Locality.—Plean, between Bannockburn and Larbert, Stirlingshire.

Geological Position.—In the Carboniferous limestone series.

Density.—2·20.

Absorption of Water.—4·25.

Crushing Load.—About 612·8 tons per square foot.

Weight.—About 138·2 lbs. per cubic foot. (Beare.)

Tint.—White; also brown, which fades.

Texture.—Hard, and close grained.

Buildings.—It is weathering at the projections of Co-operative Store, Links Place, 1885; not weathering very well at Catholic Apostolic Church, 1886, nor at one of the Pillars in Meadows, 1888.

Gunnerton Quarry.

Locality.—Gunnerton, Barrasford, Hexham, Northumberland.

Geological Position.—In the Yoredale Rocks.

Density.—2·09. (Beare.)

Absorption of Water.—5·16.

Crushing Load.—354·6 tons per square foot.

Weight.—130·8 lbs. per cubic foot. (Beare.)

Tint.—Creamy white.

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Texture.—Fine grained, medium hardness.

Buildings.—Shows no appearance of weathering at tenements at Morningside, 1885; Yardheads School, Leith, 1887; Tod's Warehouses, 1889; but at the Pillars in Meadows, 1888, it shows slight signs of weathering.

Hermand Quarry.

Locality.—Three-quarters of a mile west of West Calder, in Midlothian.

Geological Position.—In the oil-shale series, or upper portion of the Lower Carboniferous on the same horizon as the Binny sandstone. The rock is here found in massive beds dipping to the south-west, and lying a few fathoms above the Dunnet shale, which was formerly mined a short distance east of the quarry. The sandstone is here associated with beds of greenish marly blaes, which are not found at the Binny or Dalmeny quarries.

Chemical Analysis.—The Hermand sandstone is an excellent building material, and analysis by Dr S. Macadam gives the following:—

Silica	94·68
Carbonate of iron	2·19
Alumina	0·92
Carbonate of lime	1·56
Carbonate of magnesia	0·27
Moisture and loss	0·38
	100·00

Density.—2·28.

Specific Gravity.—2·445.

Absorption of Water.—4·70. (Beare.)

Crushing Load.—457·4 tons per square foot.

Weight.—142·6 lbs. per cubic foot.

Tint.—Grey.

Texture.—Hard nature and compact.

Weathering.—Its weathering qualities appear to vary.

Buildings.—At the Bank of Scotland, 103 George Street, 1883, back of Conservative Club, 1883, Calton Jail, 1886,—in which there are occasionally black marks—and at Pillars in Meadows, 1888, it shows signs of weathering; at St Mary's Cathedral School, 1885, and the west wing of Museum, 1889; West Port Free Church; and at Free St Andrew's Church, Drumsheugh Gardens, it is satisfactory.

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Craigton Quarry.

Locality.—Between Winchburgh and Philipstoun, and is a continuation of the Binny rock. Here it occurs in a great massive bed with few shaly partings. The quarry has recently been opened, and many years ago the same sandstone was worked at White Quarries, a short distance further north.

Geological Position.—In the oil-shale series.

Tint.—White.

Buildings. — Surgeons' Hall additions, 1890; Craigcrook Castle additions, 1891.

Prudham Quarry.

Locality. — Prudham at Fourstones, Hexham, Northumberland.

Geological Position.—In the Yoredale Rocks.

Density.—2·30.

Absorption of Water.—4·00-4·32 of dry weight absorbed.

Crushing Load.—455·3 tons per square foot.

Weight.—About 142·5 lbs. per cubic foot. (Beare.)

Tint.—Cream.

Texture.—Moderately hard.

Buildings. — Is extensively used, and appears to stand weathering, as at villas, Craighall Gardens, 1885-89; U.P. Church, Henderson Street, 1886; Heriot Watt College, 1886; London Street School, 1887; M'Ewan Hall, 1889; but at the Pillars in Meadows, 1888, it shows signs of weathering.

Grange Quarry.

Locality.—Grange, near Burntisland, Fife.

Geological Position.—Is situated in the oil-shale group of the Lower Carboniferous series.

Density.—2·08.

Crushing Load.—288·0 tons per square foot.

Weight.—129·8 lbs. per cubic foot. (Beare.)

Tint.—Whitish grey, some mottled with brown.

Texture.—Gets harder by exposure—fine grained.

Buildings.—It proves a good weather stone, and is satisfactory at Charlotte Street, Leith, 1870; 7 tenements in Prince Regent Street, 1882; Newhaven School, 1884; University Dome, 1886; Seafield Lodge, 1888; and Bonnington Road School, 1887.

Cragg Quarry.

Locality.—Cragg, Woodburn, Bellingham, Northumberland.

Geological Position.—In the Carboniferous limestone series.

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Chemical Analysis:—

Sand	98·97
Oxide of Iron	0·54
Carbonate of Lime	0·23
Moisture	0·14
Loss in Analysis	0·12
	100·00

(Macadam.)

Density.—2·18.

Specific Gravity.—(Water 1000) 2·491.

Absorption of Water.—5·45 %. (Macadam.)

Crushing Load.—573·8 tons per square foot. (Beare.)

Weight.—136·1 lbs. per cubic foot. (Beare.)

Tint.—Yellow.

Texture.—Fine grained and very hard.

Buildings.—It shows no signs of weathering at New Waverley Hotel, 1887; No. 7 and 9 South St Andrew Street, 1886; Merchiston Crescent, 1888.

Dunmore Quarry.

Locality.—Dunmore, near Stirling.

Geological Position.—In the Coal Measures.

Chemical Analysis:—

Silica	91·51
Alumina	·47
Oxide of iron	1·49
Carbonate of lime	3·24
Carbonate of magnesia	2·12
Combined water	1·20
Water at 212° F.	·11
	100·14

(Wallace.)

Density.—2·17.

Specific Gravity.—Air dried, 2·271.

Absorption of Water.—4·1. (Wallace.)

Total Carbonates.—5·36. (Wallace.)

Crushing Load.—289·3 tons per square foot. (Beare.)

Weight.—135·4 lbs. per cubic foot.

Tint.—Creamy Colour.

Texture.—Hard, fine grained, but in some parts shows a great number of small round holes, which are discernible when polishing.

Weathering.—It does not weather well.

Buildings.—Coltbridge Hall, Murrayfield, 1875—the frieze is wasting below the first floor cornice. The stones at U.P.

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Church, Morningside, 1884, are a good deal decayed. At the Pillars in Meadows 1888, it is weathering badly, especially the cornices; and at the Stock Exchange, 1889, it is already decaying in many places; in east front it is good, except in one stone.

Currie Glen.

Locality.—Currie Glen, Borthwick, Mid-Lothian.
Geological Position.—In the Calciferous sandstone series.
Chemical Analysis:—

	No. 1.	No. 2.
Sand and silica . . .	97·85	97·66
Oxide of iron . . .	0·32	0·24
Alumina	0·28	0·26
Carbonate of lime . . .	0·36	0·34
Carbonate of magnesia . .	0·19	0·22
Sulphur	0·06	0·04
Moisture and loss . . .	0·94	1·24
	100·00	100·00

"The first is free from objectionable material, and of average hardness; the second is of a softer nature, more friable, and therefore not so suitable for ordinary building."

"Stevenson Macadam."

	No. 1.	No. 2.
Specific Gravity:—	2·417	2·300

Absorption of Water.—5·34. (Beare.)
Crushing Load.—284·5 tons per square foot. (Beare.)
Weight.—131·4 lbs. per cubic foot. (Beare.)
Tint.—Some greyish mottled with brown; also purplish grey mottled with yellow; also whitish grey mottled with yellow.
Texture.—Fine grained.

Giffneuk Quarry.

Locality.—Giffneuk or Gifnock, near Glasgow.
Geological Position.—In the Carboniferous limestone series.
Crushing Load.—459·7 tons per square foot.
Weight.—143·2 lbs. per cubic foot.
Tint.—Pale grey.
Texture.—Soft fine grit.
Weathering.—Does not weather well in a smoky atmosphere.

Cocklaw Quarry.

Locality.—Cocklaw, Chollerford, Northumberland.
Geological Position.—In the Yoredale Rocks.
Texture.—Too hard for general use, and difficult to get clean.

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Buildings.—It is weathering at the Pillars in Meadows, 1888. The quarry has now ceased being worked.

Auchinlee Quarry.

Locality.—Auchinlee, Cleland, near Motherwell, Lanarkshire.
Geological Position.—In the Coal Measures.
Density.—2·05.
Absorption of Water.—6·90.
Crushing Load.—203·6 tons per square foot. (Beare.)
Weight.—128·9 lbs. per cubic foot.
Tint.—White.
Texture.—Coarse, and easily wrought; soft, and gets hard by exposure. Considered a poor stone.
Buildings.—Tenements in South Buchanan Street, 1878-81; Roseburn Terrace, Coltbridge, 1882; villas at Trinity, 1883, are weathering well.

Clunevar Quarry.

Locality.—Clunevar, near Dunfermline, Fifeshire.
Geological Position.—In the Carboniferous limestone series.
Tint.—White.
Texture.—Soft.
Buildings.—Tenements at 38 Marchmont Crescent, 1881; 42 Roseburn Terrace, Coltbridge, 1882; and North Junction Street, Leith, 1891.

Fordell Quarry.

Locality.—Fordell, near Aberdour, Fifeshire.
Geological Position.—In the Carboniferous limestone series.
Tint.—White when delivered, but turns black in about a year.
Weathering.—Stands the weather.
Buildings.—Granton Church, 1878.

Parkhead Quarry.

Buildings.—Weathering at the Pillars in Meadows, 1888.

Purdovan Quarry.

Locality.—Purdovan, near Fourstones, Hexham, Northumberland.
Geological Position.—In the Carboniferous series.
Crushing Load.—455·3 tons per square foot.
Weight.—142·5 lbs. per cubit foot.
Tint.—Fine yellow.

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Texture.—Fine medium.
Buildings.—Broughton Street Pro-Cathedral, 1891.

Whitstone Newton Quarry.

Locality.—Whitstone Newton, Berwickshire.
Geological Position.—In the Calciferous sandstone series.
Tint.—Warm cream colour.
Texture.—Fine, and easily wrought.
Buildings.—Shows signs of weathering at Pillars in Meadows, 1888.

Woodburn Quarry.

Locality.—Woodburn, near Woodburn, Northumberland.
Geological Position.—In the Carboniferous limestone series.
Density.—2·12.
Absorption of Water.—4·79. (Beare.)
Crushing Load.—315·7 tons per square foot. (Beare.)
Weight.—132·4 lbs. per cubic foot. (Beare.)
Tint.—Mottled yellowish brown.
Texture.—Fine grained.
Buildings. — Is not weathering well, as seen at Catholic Apostolic Church, 1886, and at the Pillars in Meadows, 1888.
Introduced about 10 years ago; supplies limited.

Cowglen Quarry.

Locality.—Cowglen, north-west of Dunfermline, Fife.
Geological Position.—In the Carboniferous limestone series.
Density.—2·19.
Absorption of Water.—3·47.
Crushing Load.—577·4 tons per square foot. (Beare.)
Weight.—136·7 lbs. per cubic foot.
Tint.—Brownish white.
Texture.—Close, and moderate hardness.
It is said to be a good weathering stone in the district, and to all appearance it is a good building stone.
It has not been worked for some time, but is being re-opened, and the stones will be in the Edinburgh market at an early date.

The following are among the principal Red Sandstones now so extensively used. They were only introduced about ten ten years ago, and, although sufficient time has not yet expired for a thorough test, some appear to stand well, while others already show signs of decay.
They all absorb a large percentage of water.

Corncockle Quarry.

Locality.—Corncockle, near Lockerbie, Dumfriesshire.

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Geological Position.—In the Permian formation.
Density.—2·12.
Absorption of Water.—4·57.
Crushing Load.—383·8 tons per square foot.
Weight.—132·6 lbs. per cubic foot (Beare.)
Tint.—Deep red, slightly marked with black bands, which disappear after exposure.
Texture.—Fine grained and medium hardness.
Weathering.—Appears to be a good weather stone.
Buildings.—Lochend Road School, 1886; Milton House School, 1886; Geographical Institute, 1888; Castle Hill School, 1888; Couper Street School, 1890.

Corsehill Quarry.

Locality.—Corsehill, Annan, in Dumfriesshire.
Geological Position.—In the Permian formation.
Density.—2·24.
Absorption of Water.—7·94.
Crushing Load.—444·9 tons per square foot; and one specimen carried 579·6 tons. (Beare.)
Weight.—130·4-154 lbs. per cubic foot.
Tint.—Fine red.
Texture.—Close grained.
Weathering.—Appears to be a good weather stone.
Building.—National Portrait Gallery, York Place, 1889; Cafe, 70 Princes Street; Red House, Cluny Gardens, 1880; Couper Street School, 1890.

Gatelawbridge Quarry.

Locality.—Gatelawbridge, Thornhill, Dumfriesshire.
Has been opened for at least 200 years. It is said to have been worked by "Old Mortality."
Geological Position.—In the Permian formation.
Chemical Analysis.—"The Gatelawbridge Red Sandstone consists solely of quartz grains, more or less gritty. The cementing material is peroxide of iron.
"There is neither lime nor other ingredient liable to be decomposed or dissolved by the weathering agents. To this fact is due the unrivalled durability of the Gatelawbridge sandstone.
"In the homogeneity of its composition, and the unassailable quality of its cementing material, it stands contrasted with most of the other Scotch Red Sandstones, which, though geologically of the same age (Permian), are totally disconnected geographically, and generally contain more or less lime, clay, and grains of a highly decomposable volcanic rock (porphyrite), thus rendering them less adapted to withstand extreme vicissitudes of climate."

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Density.—2·07.
Absorption of Water.—5·81.
Crushing Load.—495·7 tons per square foot.
Weight.—129·5 lbs. per cubic foot. (Beare.)
Tint.—Red.
Texture.—Fine.
Buildings.—It is extensively used abroad and in Glasgow, and only lately in Edinburgh, at Messrs Jenner's, Rose Street, but at Pillars in Meadows, 1888, it shows signs of weathering. It is largely exported to America.

MOAT QUARRY.

Locality.—Moat, near Carlisle.
Geological Position.—In the New Red formation.
Density.—1·97.
Crushing Load.—274·4 tons per square foot.
Weight.—123·2 lbs. per cubic foot. (Beare.).
Tint.—Red, with black band, which disappears on exposure to the weather. It is of a clayey nature, and tougher to work than some of the other red stones.
Texture.—Fine grained.
Buildings.—It is weathering at Pillars in Meadows, 1888; but is standing well at the Portrait Gallery, 1888-90, and Couper Street School, 1890.

LOCHARBRIGGS QUARRY.

Locality.—Locharbriggs, in Dumfriesshire.
Geological Position.—In the Permian formation.
Density.—2·29.
Absorption of Water.—4·06.
Crushing Load.—394·6 tons per square foot. (Beare.)
Weight.—143·0 lbs. per cubic foot.
Tint.—Pale red.
Texture.—Fine grained.

BALLOCHMYLE QUARRY.

Locality.—Ballochmyle, near Mauchline, Ayrshire.
Geological Position.—In the Permian formation.
Density.—2·00.
Absorption of Water.—6·77.
Crushing Load—185·7 tons per square foot. (Beare.)
Weight.—124·9 lbs. per cubic foot. (Beare.)
Tint.—Bright red.
Texture.—Fine grained.

DODDINGTON QUARRY.

Locality.—Doddington, near Wooler Station, Northumberland.
Geological Position.—In the Calciferous sandstone series.

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Chemical Analysis:—

Sand	97·44
Oxide of iron	0·87
Carbonate of Lime	0·12
Carbonate of Magnesia	0·09
Moisture	1·26
Undetermined and Loss	0·22
	100·00

(Macadam.)

Specific Gravity.—2·471 (Water 1000). (Macadam.)

Tint.—Pink.

Texture.—Hard, compact, and takes on a smooth surface when polished.

Weathering.—A good weathering stone.

Building.—Figures at Industrial Museum, 1887; St Giles, Warrender Park, tenements in Henderson Street, Leith, 1888.

These are among the principal stones that have been and are at present used for building in Edinburgh. Among several others that have been used are Humbie, Bellfield, Joppa, Leogar, Swinburn, Falahill, and Cullaclo used at Fettes College.

Considering the difficulty in procuring the requisite information, this paper is necessarily incomplete in many parts, but we trust that it will form a foundation on which to build a more complete record that may prove of value in the future.

Appended is a table of the physical properties, strength, &c., of the more important of the Edinburgh building stones, together with analysis and other information from which the relative qualities of the different stones can be ascertained at a glance.

TABLE.

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TABLE OF PHYSICAL PROPERTIES AND CHEMICAL ANALYSES OF EDINBURGH BUILDING STONES.

Stone.	Crushing Load per Sq. Ft.	Density.	Weight per Cub. Ft.	Absorption of Water.	Authority.	Tint.	Texture.	Nature.	Silica.	Carbonate of Lime.	Iron and Alumina.	Carbonate of Iron.	Carbonate of Magnesia.	Moisture.	Sulphur.	Oxide of Iron.	Loss.	Carbonates per Cent.	Specific Gravity.	Authority.
	Tons.		Lbs.	P.c'nt.																
Auchinlee .	203·6	2·05	128·9	6·90	Beare	White	Coarse	Soft	...	...	...	...	...	...	...	...	...	...	...	...
Binny . .	569·1	2·16	135·1	5·22	Beare	Grey	Close	Medium	...	...	...	...	...	...	...	...	...	...	...	...
Craigleith .	861·9	2·22	138·6	3·61	Beare	Grey	Close	Hard	98·3	1·1	0·6	...	...	...	...	...	...	...	2·45	Parliamentary Committee
Craigton . .	...	...	...	...	...	White	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Craigmillar .	982·0	2·46	153·6	...	Beare	Purplish white	Close	Hard	...	...	...	...	...	...	...	...	...	...	...	...
Currie Glen, I.	...	...	150·5	4·22	M'Adam	...	...	Medium	And Sand 97·85	...	0·28	0·36	0·19	And loss 0·94	0·06	0·32	...	...	2·417	S. Macadam
Currie Glen, II.	...	...	143·5	6·15	M'Adam	...	...	Softer	97·66	...	0·26	0·34	0·22	1·24	0·04	0·24	...	...	2·300	S. Macadam
Currie Glen-mean	284·5	2·10	131·4	5·34	Beare	...	...	...	...	...	...	...	...	...	...	...	...	..	...	...
Cragg . .	573·8	2·18	136·	5·45	Beare	Yellow	Fine	Very hard	And sand 98·97	0·23	...	...	...	0·14	...	0·54	0·12	...	2·491	S. Macadam
Cocklaw . .	...	...	...	...	...	...	...	Hard	...	...	...	...	...	...	...	...	...	...	...	...
Clunevar . .	...	...	...	...	...	White	Close	Soft	...	...	...	...	...	...	...	...	...	...	...	...
Cowglen . .	577·4	2·19	136·7	3·47	Beare	Brownish white	Fine	Moderate	...	...	...	...	...	...	...	...	...	...	...	...
Dalmeny .	...	...	...	...	...	Grey	Close	Medium	...	...	...	...	...	...	...	...	...	...	...	...
Dunmore .	289·3	2·17	135·4	...	Beare	White	Fine	Hard	91·51	3·24	0·47	...	2·12	Com. water 1·20	...	1·49	...	...	2·271	Wallace
Do. .	...	...	...	4·1	Wallace	...	...	...	...	...	...	...	...	0·11	...	...	...	...	...	...
Fordell .	...	...	...	...	...	White	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Granton .	...	...	...	...	...	White	Close	Hard	...	...	...	...	...	...	...	...	...	...	...	...

Gunnerton .	390·2	2·05	128·	5·16	Beare	Creamy white	Close	Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Grange .	288·0	2·08	129·8	...	Beare	Whitish grey	Fine	Moderate	...	..	...	...	...	...	...	...	...	...	...	...	...	...
Giffneuk .	459·7	...	143·2	...	...	Pale grey	Fine	Soft	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Hermand .	457·4	2·28	142·6	4·70	Beare	Grey	Compact	Hard	94·68	1·56	0·92	2·19	0·27	And loss 0·38	...	...	...	...	2·445	S.Macadam		
Hailes, . .	662·	2.30	143·8	3·71	Beare	White	Close	Hard	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Hailes, . .	459·7	2·29	143·2	4·70	Beare	Blue	Close	Hard	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Polmaise . .	551·5	2·27	141·7	4·58	Beare	White	Close	Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Prudham, .	455·3	2·30	142·5	4.	Beare	Cream	Close	Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plaen, . .	612·8	2·20	138·2	4·25	Beare	White	Close	Hard	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Parkhead, .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Purdovan, .	455·3	...	142·5	...	...	Yellow	Fine	Soft.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Redhall, . .	662·	...	143·8	...	...	Red & white	Close do.	Fine medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ravelston, .	855·8	2·26	141·1	2·93	Beare	Greyish white	Fine	Hard	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ravelston, . *Black Quarry,*	782·	2·23	139·2	3·25	Beare	Very dark grey	Fine	Hard	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Whitston, .	...	...	...	...	...	Creamy	Fine	Soft	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Newton, .	...	...	...	...	...	Yellowish br'n																
Woodburn, .	315·7	2·12	132·4	4·79	Beare	Bright red	Fine	Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ballochmyle, .	185·7	2·00	124·9	6·77	Beare		Fine	Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Corncockle, .	383·8	2·12	132·6	4·57	Beare	Red	Fine	Medium														
Corsehill, .	444·9	2·24	130·4	7·94	Beare	Red	Close	Medium														
Doddington, .	...	...	...	...	...	Pink	Compact	Hard	And sand 97·44	0·12	...	...	0·09	1·26	...	0·87	0·22	...	2·471	Macadam		
Gatelawbridge,	...	...	...	5·84	...	Red	Close	Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Gatelawbridge,	495·7	2·07	129·5	5·81	Beare	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Locharbriggs, .	394·6	2·29	143·0	4·06	Beare	Pale red	Fine	Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Montgomery, .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Moat, . .	270·4	1·97	123·2	...	Beare	Red	Close	Medium	...	...	...	...	...	..	...	...	...	...	...	...	...	...

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY,

SESSION 1892-93.

ANNIVERSARY ADDRESS.

XXXIII.—*Geological Changes wrought by Man within the Forth Basin.* By HENRY M. CADELL of Grange, B.Sc., F.R.S.E., *Hon. Secretary. Address delivered at the Anniversary Meeting of the Edinburgh Geological Society, 17th November* 1892.

THE subject on which I propose now to speak is one which deals with geology from an economic, engineering, and patriotic point of view, and as it is not often that geology and patriotism are named in the same breath, I hope that my remarks may be of some use in turning the attention of the members to this practical but somewhat out-of-the-way department of our science.

It may seem at first sight that any influence man can exert on the structure of the great earth we inhabit must be so insignificant as to be quite unworthy of attention, and altogether beneath the dignity of geological research. On collecting the evidence, however, many interesting facts begin to crop up, and it is curious to note the number of ways in which the human mind has contrived to modify the surface of certain districts, and to leave prominent marks and permanent changes over large tracts of country and round long miles of coast-line. The planting and destruction of forests, and the laborious work of the agriculturist, are geological operations of world-wide importance. Trees, it is well known, exert an important influence on the rainfall of any region, and their ruthless destruction has entirely changed the climate of many countries. With a change in climate comes a corresponding modification in the geological action of the atmosphere. The rate of erosion and denudation is altered, and consequently the rate and character of the sedimentation undergoes a corresponding change. Land that is well drained is warmer than land that is sodden

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with water, and the rain that falls on it is gradually drawn off without the possibility of much surface soil being swept away. If the mean annual temperature rises, owing to good drainage, and the warm air finds its way down below the surface, a change in the flora and fauna must ensue, and plants that formerly grew in a lower latitude are able to change their habitat to a higher latitude than that to which they were originally limited. This aspect of the question has, however, been already discussed by various writers, and it is to another quarter that I wish now to turn.

The areas on the geological map of the Forth basin which are coloured black, dark grey, and blue, all contain Carboniferous strata of more or less economic value, and it is to these districts that I shall first draw attention. Beginning near Edinburgh, the country to the west is occupied by many square miles of Lower Carboniferous rocks, which, within the last quarter of a century, have been found to contain several extensive seams of oil-bearing shale of great economic importance. The annual production of mineral oil from the distillation of the shales has hitherto been very large, and until the present disastrous crisis in the trade began, the output continued to increase from year to year. Unlike coal, the shale after extraction of its hydrocarbonaceous constituents retains approximately its original bulk, and at each of the oilworks scattered sporadically over the district, a huge heap of "spent" shale has continued to accumulate until the whole area has become studded with little flat-topped hills, resembling on a small scale the diminutive volcanic cones that are sprinkled over many parts of the Rocky Mountain deserts in the Far West. These enormous "bings," as the miners call them, are made up of a uniform mass of material, and their internal structure may be said to show false-bedding on a gigantic scale; while it frequently happens that the material having been emptied out at a high temperature, has continued to burn, till all the residual bituminous matter not previously completely distilled out has been entirely expelled into the air, and what remains is a semi-solidified mass of baked argillaceous breccia. Now, were this to occur in Nature, it would doubtless have long ago received a learned name, as it really forms a geological formation of some consequence. So long as the heat remains, the bings give off blue smoke, which often encircles their summits in a thin malodorous cloud. The bings of spent shale are far more conspicuous than the heaps of rubbish left round coal pits, as they represent the whole output of the mines, while the vast bulk of the produce of coal pits goes off by rail or sea, to be ultimately discharged into the air in the form of steam and carbonic acid gas. Man in this case acts the geological part of a volcano, as he brings up masses of rock and discharges them as ashes

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round the orifice from which they have risen from the depths beneath.

In most volcanic regions the ejection of subterranean materials is accompanied by changes of level of the surface, and here again our race shows its volcanic propensities. So far as I know, man has never been successful in producing a genuine terrestrial earthquake; but there is abundant evidence of his having recently produced conspicuous changes in level over large tracts of country, especially in the Carboniferous districts.

The old method of mining coal and other stratified deposits was to cut a series of cross galleries or roads through the seam, until the area worked out resembled on the plans a net, with a solid pillar of coal left in the centre of each mesh to support the roof and prevent a general collapse of the superincumbent strata. In some cases the pillars were afterwards robbed out, so that the roof suddenly fell in and produced a subsidence of the ground above. In other cases this has proved too dangerous or impracticable, and the pillars have been left standing, so that the ground remains honeycombed by the old workings. In this connection, I may digress to mention a remarkable case which came under my notice last year when I visited one of the great coalfields of Pennsylvania. Among the big things of the West there is in the anthracite region a seam of coal, known, like all big things in that part of the earth, as the Mammoth Vein, the thickness of which is at places more than 50 feet. This monstrous bed of coal is often mined to its full thickness, and huge pillars are left to support the lofty roof of the workings. More than twenty years ago the pillars were robbed to such an extent that the inhabitants of the town of Shenandoah, which is built right on the top of the workings, began to be terrified at the thought that their whole city might any day be engulphed in the abyss below. Years went by, and no very disastrous subsidence took place; but it was recently discovered by a new company of operators who examined the old coal "wastes," that at one part of the workings their predecessors had left between the pillars a gigantic "room," or cavity, no less that 700 feet in length and 300 feet in breadth, spanned by an arch of rock 60 feet high at a depth of 400 feet below the surface. This extraordinary fact is perfectly well substantiated, and is mentioned in one of the reports of Mr Wm. Stein, the Government mining inspector of the district, who, by the way, is a Scotsman of character and veracity. I went through part of this working, and can testify to the huge size of these subterranean cavities.[1] I mention this to show how strong some

[1] The matter is referred to in my paper on a visit to Pennsylvania in the "Trans. Mining Institute of Scotland," Vol. XIII., p. 259, where an account is given of the ingenious method adopted for filling up these great cavities.

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kinds of rock are found to be, and what a vast amount of subterranean honeycombing man has produced in some places.

It is, however, unusual to leave the pillars in if they can be removed, and in the end, if the seam is at any depth, the removal of the pillars produces practically the same effect on the surface as the removal of the coal by the long-wall system which is now almost always employed where the seams are less than 6 feet in thickness, and the other requisite conditions are present. In the long-wall system of mining, the whole seam is removed and the superincumbent rock allowed gradually to subside on to the pavement, leaving the strata as they were before, but *minus* the coal they originally contained. It is not possible to produce a subsidence at the surface equal to the whole thickness of the coal removed, as the roof never quite crushes down on the pavement, owing to the rubbish, timber, and temporary supports put in to enable the working to progress; but experience has shown that for depths not exceeding 600 feet, after the ground above has completely settled down, the depression of the surface is equal to about 75 per cent. of the thickness of the excavation below. Now this systematic subsidence of the surface is distinctly a geological phenomenon of importance. In the working out of a seam by the long-wall system, the progress of the working faces below can be traced by a distinct wave of subsidence on the surface which follows the line of the coal "faces" at a regular distance, and continues to move for some months after the excavation has ceased to be carried on. If, as is usual, several seams are worked above one another in a district, the whole amount of subsidence may be very considerable. There are in Scotland places where, over large areas, the level of the surface has been reduced more than 20 feet in this way. At West Calder, where the oil shales are extensively mined, any traveller may notice that the railway bridges have been raised some 6 feet recently, owing to the subsidence of the ground and the railway, which, with the bridges, has had to be heightened systematically.

At coalfields on the coast, such as that at Bridgeness, where the coal is worked on the long-wall system under the sea, the same lowering of the surface takes place, only it is not always visible. Where the workings are below the foreshore the sinking of the mud can be seen by the outline of the advancing tide, and I can recollect of having seen a long tongue of water stretching towards the beach over the foreshore being lowered in this way many years ago. The present workings are further out, and this hollow has long ago become obliterated by the silting up of the mud. It is, however, clear that in the case of submarine workings the geological result of man's operations is to produce a deepening of the sea-bed, and to help the navi-

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gation if the water be shallow, or to cause a thickening of alluvial deposits over the place if the currents are sluggish.

There are, however, other branches of human industry besides mining to which are due several permanent alterations in the geology and topography of parts of the Forth area.

Along the upper reaches of the Forth valley above Stirling the river flows through a wide alluvial plain, no doubt occupied by the sea before the last upheaval of the land took place. At the time of the Roman invasion these carse-lands seem to have been thickly covered with the dense Caledonian forests which presented a formidable impediment to the enemy's advance. To get rid of this obstacle in their road to glory, the Romans set to work to cut down the trees and deprive our ancestors of their sylvan retreats. In course of time the site of the forests became overgrown with peat, and up to the middle of last century the whole area was a succession of vast morasses and quaking bogs, of little use either to man or beast, which had continued to flourish without interference for some seventeen centuries. Of these peat-covered tracts the Flanders Moss is the largest and most westerly, extending up the valley of the Forth from the neighbourhood of Thornhill for a distance of about eight miles. The Blairdrummond and Kincardine Moss is the next in size, and there are many other adjacent peat-covered areas which were, no doubt, all once more or less connected, but have now become detached and reduced in size during the long-continued processes of reclamation about which I wish now to speak.

Up till 1766, when Lord Kaimes became connected with the Blairdrummond estate, little or nothing seems to have been done towards the reclamation of the great peat mosses in that district, which were known to cover up a valuable tract of rich alluvial soil. He applied his powerful intellect to the matter, and originated a method of clearing away the moss which proved quite successful, and was, after his death in 1783, carried out with still greater effect by his son Mr George Home Drummond, assisted by Mr George Meikle, of Alloa, the son of the inventor of the threshing-mill. A water-wheel lined with buckets was contrived by Mr Meikle which raised from the River Teith a large supply of water, and this was directed into channels communicating with reservoirs in the moss, and the water-power thus obtained was used to float away the peat, which was dug out and thrown into the water by manual labour. The great wheel was in operation for fifty-two years, from 1787 till 1839, and was instrumental in assisting to clear off some 1300 acres of the Blairdrummond moss. Many hundred acres of the other peat mosses have been floated away into the Forth by impounding the waters of the tributary

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streams, shovelling in the peat, and letting the pent-up flood rush out suddenly, sweeping away all its light and bulky burden with the force of the outburst. To obtain the necessary labour, settlers were brought from the Highland parishes of Callander, Balquhidder, and elsewhere by Mr Drummond, and these families soon increased in number and prosperity until the once barren morass disappeared and gave place to a smiling plain of good carse-land inhabited by hundreds of happy families.

The floating away of the Blairdrummond Moss and of the other morasses near it was a monumental achievement in the history of land reclamation, and the face of the country and the geological map alike bear testimony to man's power as a geological agent here. The huge Flanders Mosses are, however, still to a great extent unreclaimed, and there is still plenty of room for Man to assert his power over Nature in this part of the Forth basin. While the floating was in progress, it is fair to state that great annoyance was caused to the inhabitants and fishermen lower down the river from the immense quantities of black, pulpy, peaty matter that were constantly washed down and cast on the shores of the Firth. I believe that the nuisance ultimately became so great that the process had to be discontinued; at all events, I have not for a long time observed any floating peat such as used to be cast up at every tide twenty or twenty-five years ago. It would be a great benefit to the reclamation works in progress elsewhere, of which I shall again speak, could the floating of the mosses be begun again and carried on in such a way as to let all the peat be floated to the part of the Firth where it is much wanted to mix with the mud being deposited within the areas of deposition, and help to keep the soil open, and thus increase its ultimate agricultural value.

Another direction in which something has been, and much more remains to be accomplished by man in modifying the geological map of the Forth basin, is the reclamation of the long flat foreshores that fringe the margin of many parts of the estuary. This is a subject in which I have always taken a deep interest, and am at present engaged in prosecuting on a small scale at Grange, in the Bo'ness district. It is a matter of some geological interest, and has also important economic bearings on the welfare of a large district, so that I may be excused for dealing with it in some detail.

The subaerial agencies of geology act generally in a destructive direction, and operate in lowering, wearing down, and washing away the land, and thereby reducing its dimensions. Every true patriot magnifies his native land, and how magnify it better than by increasing its actual size and superficial area of miles, acres, and roods? It was, I think, Lord Jeffrey who,

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when upholding Scotland in the presence of a scoffing Englishman, would not even admit that his native land was the smaller portion of Great Britain; for, said he, if you flatten out our hills and mountains they will spread over a much greater area than that occupied by the country of John Bull. In the work of marine reclamation we are acting on this original suggestion, and, with the help of natural agencies, are levelling up parts of Scotland so as to magnify and extend its borders; and it is here that the patriotic side of geology to which I have alluded, becomes apparent.

The foreshores of the Forth may be reclaimed in two ways. The first and simplest method, which can only be carried out where the necessary materials are abundant, is to empty out rubbish along the shores and gradually push the edge of the tide backwards. This is practically producing artificial raised beaches, which rise above high-water mark and fringe the natural coast-lines for considerable distances at some places. In the Bo'ness district a gradual process of reclamation of this sort has been in progress for several centuries. The coalfields of Bo'ness, Grange, and Carriden, are among the earliest worked in Scotland, and there are records of coal-mining here some four centuries ago. The coal, besides being shipped in large quantities, was also used in the saltpans, which extended for miles along the coast, and produced, besides salt, quantities of ashes, which were emptied out along the beach. The last of the saltpans of the district, situated in Grangepans, was in operation when I read a paper before this Society ten years ago; but, as I then predicted (see the Transactions for 1882, p. 222), it has now ceased to exist, and the salt industry for which Bo'ness was once famous has become a thing of the historic past. The geological work of the old salters is, however, permanently traceable in the fringe of pan ashes that can be found for miles along the coast by digging a few feet down within fifty yards of the present beach.

Fortunately for the present generation, the coal-fields are not yet quite exhausted, and the old salters' debris is now being covered up with the black rubbish from the collieries along the shore. At Kinneil, again, the ironworks, which are now demolished, but for some forty years formed a conspicuous landmark by night and day, discharged large quantities of slag blocks over the foreshore, forming a raised beach which covers in all some thirty acres once occupied by the sea.

This method of reclamation is slow but sure, and yields commercially the quickest return, since the ground can be used for building and other purposes as the banking progresses. The next method is of a totally different character, and although ultimately of greater geographical importance, is generally more

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costly and slow in operation. I refer to the process of "warping," or enclosing, the flat foreshores with training walls and long embankments, inside of which the muddy tidal waters are encouraged to deposit their suspended matter, and thus assist in the banking up and reclamation of large areas.

The first important reclamation of this class, so far as I know, was begun by Lord Keith, the proprietor of Tulliallan estate, in 1821, and is described by Mr William Menzies, Lord Keith's factor, in Vol. XII. of the Highland Society's Prize Essays, published in 1839. In this very interesting paper Mr Menzies gives an account of two reclamations, the first of which was carried out in the bay which existed in 1821 between Kincardine and Kennetpans. An embankment was begun in April of that year which enclosed an area of 152 acres, and had a length of 2020 yards. The spring tides rose to a height of eight feet over the foreshore along the line of the bank, which was composed at first entirely of mud wheeled with barrows from each side, and subsequently partly of brushwood to strengthen it, and had an average height of eleven and a-half feet. It had afterwards to be faced on the outside with stone, and heightened three feet or more, as it subsided considerably during the course of construction. As the work progressed the mud accumulated inside so as to raise the level of the enclosure and render the drainage more easy. For a year after the tide was shut out the saltness of the ground prevented the growth of vegetation, and it was not till 1824 that drainage and agriculture were begun, and an attempt at cultivation was made. In 1827 the first good crop of grass was obtained, and the productiveness progressed till 1830, when the ground was broken up in rotation for oats, barley, potatoes, beans, wheat, and clover grass, which improved yearly as the salt was extracted from the ground, and subsequently yielded almost unequalled returns. The cost of this reclamation was between £6000 and £7000, and the rent was progressive as the land improved in fertility.

The next reclamation of importance was carried out on the east side of Kincardine pier by means of an embankment running to near Longannet Point, which enclosed an area of 214 imperial acres. This was begun in the spring of 1829, and progressed slowly so as to allow the mud to silt up inside. The spring-tides rose eleven and a-half feet over the line of the bank at the Longannet end, and seven feet at the Kincardine end. By the middle of the summer of 1836 the mud had risen over the lower parts of the enclosure to a height of seven feet nine inches, and had raised the surface above the high-water level of neap tides. Openings were left to allow the tide to enter and deposit its mud, and at last these were, not without difficulty,

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closed successively, the sea being finally shut out in the end of February 1838, nine years after the commencement of the work. The whole cost exceeded £12,000, and many difficulties had to be overcome, but the work was greatly aided by the facility for procuring stone, of which about 170,000 tons were used in the embankment.

The great expense of such works prevents experiments of this kind being made often, and it is only where favourable conditions are present that they can be attempted. The presence of large tracts of rich alluvial mud, covered for only a part of each day by a few feet of water, is, however, a very tempting field for engineering enterprise. It seems a great pity to see so much good land that might add greatly to the wealth of a district lying waste for want of a little enterprise and capital expenditure. The returns may not be always great, but they are sure, and the country will benefit in the long run, as more productive ground will be added to its borders, and a correspondingly greater amount of employment will be afforded to its industrious inhabitants.

About thirty years ago my late father began negotiations with the Crown as to the purchase of the foreshore opposite his estate of Grange, which includes the private harbour of Bridgeness and extends for nearly a mile eastwards from Bo'ness. In 1872 the negotiations resulted in his purchasing about 86 acres of foreshore in order to reclaim the area by the same method as that just described. For various reasons this plan was never carried out, and all the reclamations that he accomplished were by the direct method of banking out the ground immediately along the high-water mark, by which means some 12 acres have been added to the district within the last twenty years.

For the last four years I have been endeavouring, more or less regularly, to carry out a part of the original plan of reclaiming the Grange foreshores by the method of warping, and I hope in the course of the next five years to see about 25 acres added to the productive carse-lands of the Forth. The piece of ground being reclaimed lies to the east of Bridgeness harbour, which consists of a central pier, shown on the ordnance maps, with a breakwater on the west, and a broad peninsular tongue of land stretching out to low-water mark on the east, which has been embanked since the ordnance survey was made thirty-eight years ago. As this is a comparatively small area, I applied to the Board of Trade in 1888 for the grant of an additional stretch of foreshore adjoining my ground on the east, which might advantageously be reclaimed at the same time, but my application was refused "in the interests of navigation." It is difficult to see how any injury could be done in this way to navigation, as the Firth is here more than two miles broad, and

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any such reclamations would have the effect of increasing the scour outside—a result which would be rather beneficial than otherwise, as the fairway is here very shallow and full of gravel banks, which might with advantage be washed away into deeper water.

The piece of foreshore being now reclaimed is bordered on two sides by land, and the embankment necessary to enclose it will, when completed, have a length of about 600 yards. The outer edge of the bank is situated parallel to and about 100 feet from the average low-water mark of ordinary spring tides. Along this line the highest spring tides rise over the mud to a height of 15 feet, the total rise and fall of the highest springs being here, with rare exceptions, almost exactly 19 feet.

The materials used in the embankment consist chiefly of heavy colliery debris from a pit sunk on the peninsular bank east of the harbour to reach the coal seams underneath the Firth, and had it not been for this constant supply of rubbish it would have been impossible to carry out the reclamation with any chances of ultimate economic success. After much cogitation, I resolved to try a plan which has every promise of a successful issue. The system was not to shut out the sea by one heroic bank, but first to run out a low bank to the eastern limit, which would be covered by every tide, and turn the end in for a short distance towards the shore, so as to enclose all the lowest part of the foreshore. This bank was begun in the end of 1888, and completed in the end of the following year. It was 300 yards in length, and had a breadth on the top of about 20 feet, sufficient for a double line of a three-feet gauge colliery railway. The top of the bank rose some 3 or 4 feet above the surface of the mud, but as the soft foundation subsided, much additional material had to be added to keep it up to the original level. To help the rough lumps of carbonaceous shale to consolidate large quantities of bushwood and branches of trees were added, and numerous old hedges were cut down and buried among the foundations. The rush of the ebbing tide for a time produced a deep gully round the end of the bank, but this difficulty was obviated by the construction of a temporary bridge in the centre, which was filled up when the work was completed, so as to completely impound the tidal waters within the enclosure.

As this first sea-wall progressed a certain amount of siltation took place inside, and when the gap in the centre was finally closed the mud was deposited very rapidly, so much so that at the end of 1889 it had accumulated to a depth of from 1 to 2 feet over a considerable area, and the deeper hollows had been filled up 3 feet or more. A second low bank was begun in 1890 on the top of the first and was run out about 150 yards, but, for economic reasons, nothing further was done for a whole year

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between the middle of May 1890 and the same month in 1891. In May 1891 a third bank above the high-water level of ordinary spring tides was extended over the second, and this was prolonged to within 140 yards of the outer limit. There were thus two banks for about half the distance out on the top of the first bank, up till last September. The mud by this time had silted up steadily within the enclosure, and had risen above the level of the greater part of the first bank, which, from the landward side, had mostly disappeared from sight. The gauge posts which had been driven into the original foreshore showed the silting to have nearly reached 6 feet at places, while for a considerable distance within the bank the level of the mud had risen from 3 to 4 feet. Had it been convenient to carry on the work steadily from the beginning, there can be no doubt that the rate of deposition would have been much more rapid, since the mud rose to the top of the first bank and the water ceased to be impounded long before the next bank was ready to cover it.

In the middle of September 1892 I resumed the construction of the second embankment and carried it at a height of about 4 feet along the crest of the first bank, turning its eastern extremity landwards across the foreshore to near the foot of the beach. The top of this new bank is approximately level with the high-water line of ordinary neap tides, and so soon as the mud has risen inside to this height it will be time to exclude the sea, as in such reclamations the high-water mark of neap tide is considered a safe minimum level for the lowest part of the enclosed slob land.

A bank of such loose materials is necessarily very porous, and the muddy sea-water, percolating through, becomes filtered as it passes, and leaves its mud among the stones, issuing in nearly transparent springs on the outside slope. By and by this filter becomes clogged with mud, and the springs cease to flow, the bank having become consolidated into a solid mass of breccia composed of lumps of black carboniferous blaes set in a brown post-pliocene argillaceous paste. In this way it becomes unnecessary, at first at least, to construct a watertight sea-wall, as the wall makes itself impervious in course of time. Three pipes from 12 to 15 inches in diameter were laid across before the second bank was made, and these will serve to allow the tide to flow out gradually after the water is impounded by this bank, and will serve ultimately to carry off the drainage of the area.

I have not made any very exact measurement of the rate at which mud deposits in quiet places in the Firth, but it is not possible to do so with any degree of precision, as the rate depends on a variety of conditions which are very different at different places. For example, at one place I have observed recently

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that the mud has risen at least a foot in two months, where the conditions are favourable. Again, near the end of the outer bank there is a sandbank which formed part of an old pier where coal was shipped some two centuries ago by the old cadgers who brought it down in creels on horses' backs from the pits near the shore. The keel marks of the ancient coal boats that frequented this wharf are still visible on hard parts of the surface of the gravel, proving that there has neither been deposit nor erosion here for the last two hundred years.

It must be borne in mind that the mud being deposited at all sheltered places where the water can remain undisturbed is not primarily river mud at all, but is, I believe, nearly all washed by the waves from other parts of the mud-flats in the vicinity. On a rough day the water is very brown near the shore, but is much clearer in the centre of the Firth, which proves that the regular supply of mud from the river is small in comparison with that stirred up from the slob lands in the neighbourhood. This is an important point, because it shows, if true, that to carry out any very extensive scheme of reclamation by warping it would be necessary to do the work piecemeal and not try to reclaim too large areas at once, leaving no adjoining mud flats from which the tide might wash in the mud necessary to raise the height of the enclosed area.

In conclusion, I would refer to the expanse of flat sleeches occupying some 3000 acres to the west of Bo'ness, the greater part of which is covered by less than two fathoms of water at the highest tides. This area could, in part at least, be reclaimed with comparative ease, as the old slag heaps and colliery blaes bings at Kinneil would furnish abundant material for the requisite embankments. The project, often brought forward, has never yet been carried out, and now the agricultural value of carse land has so decreased that there is little encouragement to persevere in this interesting work. There is, however, one aspect of the question that has perhaps some elements of interest which has recently occurred to me. The mud, as we have seen, which silts up in still water, is derived from other parts of the shore, and not to any great extent from the river. By taking in a large area, the water would be deprived of much suspended matter, and mud would be washed away from exposed parts of the foreshore outside the enclosure, which would ultimately become more sandy, clean, and hard, than it is at present. In ancient times there were huge oyster beds in the district, and it may have been the increasing quantity of mud which has choked them out. Could the mud be again extracted in the process of reclamation we might once more be able to cultivate oysters in the Firth of Forth as large as a plate, like those to be found in the old kitchen middens of Kinneil.

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XXXIV.—*A Map of the Ancient Lakes of Edinburgh.* By Henry M. Cadell of Grange, B.Sc., F.R.S.E.

From all the evidence, both historic and geological, we can clearly demonstrate the former existence of seven more or less conspicuous sheets of water in this part of Midlothian. The positions of these are indicated on the accompanying map of the site of Edinburgh in ancient times, which has been compiled from a variety of data referred to in the following pages. On this map the 25-feet beach is shown as the coast-line at the time the old lakes were in existence. These "seven eyes" of ancient Dun Edin were as follows:—

1. Gogar Loch.
2. Corstorphine Loch.
3. Craigcrook Loch.
4. The Burgh Loch.
5. Holyrood Loch.
6. Lochend Loch.
7. Duddingstone Loch.

Of these only three are now represented by sheets of water, namely, the lochs of Craigcrook, Lochend, and Duddingstone. There were in addition several smaller pools or "dubs" which hardly deserve the name of lakes, situated at Canonmills, Morningside, the north-east of Blackford Hill, Hailes Quarry, and perhaps also in Hunter's Bog, between Arthur's Seat and Salisbury Crags. It may be remarked by readers acquainted with Old Edinburgh that the Nor' Loch is not included in the list; but there is no evidence that this lake had any existence prior to the year 1450. Like St Margaret's and Dunsappie in the Queen's Park, it was of artificial origin. The valley north of the city was, in the reign of David II., who flourished in 1144, part of the king's gardens, and was used for tournaments, sports, and military parades. In 1450 a dam was thrown across it, and the waters of the little stream issuing partly from the spring at the Wellhouse Tower, and partly from the rising ground to the west, was impounded to save the expense of building a wall along the north side of the city. The Nor' Loch existed for three centuries, the outlet at the present Waverley Station being regulated by a sluice. It latterly degenerated into a huge cesspool for the refuse and sewage of the New Town, and was drained about the end of last century, the last traces of the morass, along with other public nuisances in the vicinity, being removed for the sake of the amenity of Princes Street in 1816.

[1] The subject of this paper was originally read as a communication to the Society on 17th December 1891, and has since appeared, with some modifications, in the *Scottish Geographical Magazine* for June 1893, in the form of an article on "Some Ancient Landmarks of Midlothian."

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1. Gogar Loch.

The configuration of the ground between Gogar Burn and Corstorphine points to the former existence of a shallow lake about one-and-a-quarter mile in length, stretching along the flat hollow north of and roughly parallel to the railway. There is not much historical or geological evidence from excavations as to this old lake. That it existed in historic times is, however, clear, as it is shown on Pont's map, published in the reign of James VI., and in John Adair's map of 1680. It is also indicated in John Elphinstone's map of the Lothians (1744), a copy of which is in my possession. It cannot, within the last three centuries at all events, have been a lake of much note, and was probably little more than a bog when these maps were made. Reference to the bogs and marshes in the meadows at Gogar is made in the narratives of Cromwell's and Leslie's marches in 1650; and in July 1661 James Forrester presented a petition to Parliament in which he complained that "the whole meadow ground and low lying lands was undone by the overflowing of the Gogar-burne, and that partly through the neglect of those who formerly were accustomed to cast and keep clear the ditches and stanks through which the water did naturally pass, and partly by the inbreaking of the said water in the lands of Redhewes." The Gogar Burn may at one time have flowed eastwards along this hollow to join the Water of Leith at Coltbridge, and may in course of time have brought down so much mud as to fill up the west end of the lake, and then find a new outlet into the Almond on the west. The ground is, however, so flat that it is equally probable the stream may have merely overflowed into this depression, the main portion of the water escaping by its present course into the Almond. Pont's map shows the burn flowing northwards past the loch in this direction. On the 2nd edition of the 1-inch geological map (sheet 32), just published, the probable original area of this loch is marked as an alluvial plain; and this forms the basis on which I have reproduced the lake on the map accompanying this paper, and shown the Gogar Burn flowing into its western end.

2. Corstorphine Loch.

The ancient loch of Corstorphine must have once formed a feature of considerable importance in the landscape, as its existence is proved by both historical and geological evidence of a very conclusive kind. It seems to have been originally separated from Gogar Loch by a flat tongue or ridge of boulder clay, and to have extended for a distance of nearly three miles

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from the vicinity of Broomehouse to the present Haymarket goods station, the original margin coinciding almost exactly with the 150-foot contour line on the Ordnance Map. Both of these lakes are referred to in the "New Statistical Account of Scotland," Vol. I., p. 245, and are shown on the old maps of the district. Elphinstone's map shows that during the century preceding 1744 the area of water had become greatly diminished. The draining of Gogar Loch was carried out about 1766, as it is not shown in maps of later date; and Corstorphine Loch was partly drained and reclaimed in 1670, when the deep ditch known as the Stank was excavated along its northern side. The final reclamation was completed in 1837, when the Stank was deepened and enlarged to prevent any further flooding of the rich alluvial floor of this ancient lake. The Castle of Corstorphine was built on the neck of dry land between the two sheets of water, and for many centuries must have thus occupied a position of considerable strategical importance. The once celebrated Forresters, Lords of Corstorphine, to whom the castle belonged, are said to have brought their provisions by boat from Coltbridge; and it was their interest to prevent the lake from being drained so long as their enemies were to be kept at bay and the strength of the fortress maintained. Dr Taylor, in his interesting little volume, "A Midlothian Village," says that sometimes the tongue of land between the two lochs was partly submerged, the passage across being maintained by a ferry; and there is a tradition that at no very remote date a beacon-light used to be fixed up on the gable end of Corstorphine Church to guide benighted travellers safely across the dangerous morass.

The recent deep cuttings through the district in connection with the Water of Leith purification works, as well as some excavations during the construction of the Forth Bridge Railway, near Corstorphine station, have revealed many interesting sections of the deposits found in this old lake. Mr James Bennie, of the Geological Survey, has made a careful study of these and other old lacustrine deposits, and has given an account of them in the "Proceedings of the Royal Physical Society," Vol. X., p. 133. In a cutting seven feet deep, on the farm of Broomhouse, for a culvert below the Forth Bridge Railway, the subsoil was found to consist of lake silt and peat. The silt was, Mr Bennie says, crowded with fresh-water shells and ostracoda, and the peat, being composed chiefly of the stems of aquatic plants, was essentially a water peat.

The following list of plants obtained by Mr Bennie in the old lake beds of Corstorphine and Hailes shows that an Arctic climate prevailed at an early stage in the existence of these

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lakes. The list is taken from a paper by Mr Clement Reid, F.L.S., F.G.S., published in the British Association report for 1892, p. 716:—

Flowering Plants.

Ranunculus aquatilis, Linn.
„ repens, Linn.
Viola (?).
Stellaria media, Cyr.
Rubus sp.
[1] Dryas octopetala, Linn.
Potentilla sp.
Poterium sp.
Hippuris vulgaris, Linn.
Myriophyllum spicatum, Linn.
Taraxacum officinale, Web.
Andromeda polyfolia, Linn.
Menyanthes trifoliata, Linn.
Oxyria digyna, Hill.
Betula nana, Linn.
Alnus (?)
Salix repens, Linn.
[1] „ herbacea, Linn.
[1] „ polaris, Wahlb.
[1] „ reticulata, Linn.
Empetrum nigrum, Linn.
Potamogeton sp.
Eleocharis palustris, R. Br.
Scirpus pauciflorus, Lightf.
„ lacustris, Linn.
Carex, 2 sp.

Mosses (determined by Antony Gepp, F.L.S.).

Barbula fallax, Hedwig.
„ fragilis, Bruch & Sch.
Grimmia sp.
Racomitrium sp.
Philonotis fontana, Brid.
Aula comnion palustre, Schw.
Webera sp.
Bryum sp.
Pogonatum sp.
Polytrichum sp.
Campothecium nitens, Schimp.
Hypnum polygamum, Schimp.
„ fluitans, Linn.
„ revolvens, Swartz.
„ regosum, Ehrh.
„ cupressiforme, Linn.
„ sarmentosum, Wahl.
„ cuspidatum, Linn.
„ trifarium, Web and Mohr.
„ scorpioides, Linn.

The recent excavations for the Water of Leith purification works, in which large sewers were laid westwards from Coltbridge to Corstorphine, and southwards across the bed of the lake towards Gorgie, revealed a well-marked series of beds of silt, laminated and brick clays, sand, gravel, and peat, as well as occasional marl deposits, which show clearly that for long ages after the Glacial period this remained a lake of considerable importance. The sediment which helped to fill it up was no doubt chiefly contributed by the Water of Leith, which crosses its eastern end between Gorgie and Coltbridge; and it is probable, as the old maps indicate, that, being nearest the source of deposition, this end of the lake was the first to disappear. The lowering by natural erosion of the boulder-clay

[1] Arctic species no longer living in the lowlands of Scotland.

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barrier across the outlet at Coltbridge would also diminish the level of the water, and aid the stream in obliterating this ancient landmark from the district.

3. Craigcrook Loch.

This tarn, situated in the hollow at the foot of the eastern slope of Corstorphine Hill, north of Craigcrook Castle, is now represented by a small, reedy pool on the east side of the road from Ravelston to Cramond. So far as I have been able to learn, it is not referred to in any description of the locality. Had it ever been a lake of importance reference would have been made to it in Wood's very accurate "History of Cramond Parish." It is, however, marked on Pont's map, and the configuration of the ground shows it to have once covered a much larger area than that of its present insignificant representative. The lake was, I believe, drained by a culvert leading northwards to the low ground near Davidson's Mains, but the original outlet must have been the burn running eastwards along the hollow through Blackhall and past the north side of Craigleith Quarry and Comely Bank to the Water of Leith. The road from Ravelston referred to above crosses part of the old lake bottom; and the field adjoining is locally known as the Marl Pits, from the deposit of shell marl found by digging a few feet deep in this flat ground, which on the map I have included in the old lake area.

4. The Burgh Loch.

This sheet of water, which was in existence up to the beginning of this century, occupied the site of the present Meadows. There was once a tradition about another lake in the neighbourhood of the Cowgate called the South Loch; but this tradition seems to have been founded on no conclusive data, and Maitland, in his "History of Edinburgh," published in 1753, seems to have made out that the South Loch and the Burgh Loch were one and the same lake. There seem to have been in prehistoric times a few marshy pools along the hollow of the Cowgate and Grassmarket; at Bristo Port and elsewhere; but such "dubs" were no doubt once abundant in the district, and do not deserve special mention here.

The Burgh Loch and its marl and peat beds have been described by Hugh Miller and other writers. The marl, which was at places three feet or more in thickness, contained abundance of the delicate shells of *Limnæa*, *Valvata*, and *Pisidium*, as well as occasional specimens of *Planorbis*, and several species of ostracods, most of which forms are abundant in the marl of the other old lakes of Edinburgh. A list of these by Mr Thomas Scott is appended to Mr Bennie's paper, already referred to

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The water of this lake was once used for domestic purposes, and a windmill was erected to pump it for the use of the brewers of the Society established by James VI. in 1598. The draining of the loch was begun in the early years of the seventeenth century. In 1722 it was let for £800 Scots on a fifty-seven years' lease to Thomas Hope of Rankeillour, who began to drain it more perfectly, and converted it into a marsh, with a walk round it. It remained, however, a morass till 1840, when the water was finally completely drawn off, and since the beginning of the century has been a public resort, formerly patronised by the wit, beauty, and fashion of the Modern Athens. The surface of the original lake-bed was, like that of the Nor' Loch, for many years used as a "free toom" for rubbish, so that it is now raised several feet above its original level, and the uninitiated may therefore at first sight have some difficulty in realising its ancient lacustrine character. Modern improvements have so modified the appearance and levels of the surrounding ground that it is somewhat difficult to picture to ourselves the position of the ancient outlet for the surplus water when, as it occasionally did, the loch overflowed. The Burgh Loch is not shown on Pont's map, nor is there now any indication of a stream in the neighbourhood; but other old maps show that the loch overflowed westwards into the east end of the Corstorphine Loch in the vicinity of Dalry.

5. Holyrood Loch.

The greater part of this lake is unknown to history, and the evidence on which its former existence is based is principally geological. There is, however, some reference made in old descriptions of Holyrood to a lake or piece of marshy ground at the foot of Arthur's Seat, along the edge of the old Palace gardens, and from an entry in the Lord High Treasurer's accounts it appears that the "loch beside the Abbey" was drained some four hundred years ago, in the time of James IV., as a site for a garden.

The ancient loch of Holyrood must have nearly all dried up and disappeared long before the Abbey was founded in the beginning of the twelfth century, as King David, the "sair sanct," was not likely to choose a soft morass on which to erect such a noble edifice. The configuration of the ground shows that the Abbey and Palace are situated right in the middle of the original lake basin, which had a rudely triangular shape, the longest side stretching north-eastwards along the foot of Salisbury Crags to the vicinity of Spring Gardens, for a distanee of about two-thirds of a mile.

Numerous excavations have from time to time been made in

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this flat area, and have been described by Mr Andrew Taylor[1] and Mr John Henderson[2] in the *Transactions of the Edinburgh Geological Society*, and by Messrs J. A. Johnston and J. Lindsay in the *Transactions of the Edinburgh Naturalists' Field Club*.[3] I have myself also had opportunities of examining some of these sections before they were covered up, and it would be difficult to get a better example of a typical lacustrine flat in any part of the Edinburgh district. The best sections were revealed in the bores and excavations for one of the large gasometers at the South Back of the Canongate. In one of these bores the following strata were pierced:—

	Ft.	In.
Forced material at surface,	3	2
Yellow clay,	2	4
Peat,	3	0
Marl,	9	0
White and brown mud,	2	6
Blue and red clay,	1	9
Rough gravel,	4	6
Clay and small stones,	5	6
Blue clay,	7	7
Depth to rock,	39	4

In this section we have typical lake deposits to a depth of about 26 feet below the present surface, the lowest beds being probably glacial drift of more ancient origin.

The variable local character of these old lake beds was well shown in the deep excavation for the gasometer tank. A careful section was drawn by the engineer in charge of the work, a copy of which in my possession shows that the rock surface was covered by a bed of marl, varying in depth from about 2 to 5½ feet. This was overlaid by a bed of peat less than a foot in thickness, above which came a thick stratum of "till," or rough stony clay, probably washed down by torrents from the adjoining steep talus of Salisbury Crags. At the north-west side of the tank the till was covered by a second bed of marl, showing that the floods gave place to a drier period, in which the water remained sufficiently tranquil for the delicate molluscs to flourish in peace. This marl, however, only covered part of the area, and passed into a bed of grey and yellow sand, 3 to 4 feet deep, along the south-east side of the excavation. The whole was overlaid by a covering of vegetable mould 5 to 8 feet thick, the greatest depth of the whole section of lacustrine beds at the south-east side being about 34 feet.

[1] Vol. v. p. 44. [2] Vol. v. p. 407. [3] Vol. ii. p. 135.

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In the beginning of 1887 a cutting several hundred yards in length was made for a sewer running north-eastwards from this point past the Palace gardens, in which a section at places 20 feet deep was laid bare. Mr John Henderson, in his description of this cutting, states that the surface to a depth of about 6 feet consists of artificial deposits, with fragments of pottery, oyster-shells, bones, &c., resting on brown, peaty clay about a foot in thickness. This bed passes down into peat, which has at places a depth of 18 inches, and all along the section rests on marl 1 to 2 feet thick, the lowest part of the section consisting of brown and blue clay resting on loose, clayey sand, which seems to have here formed the floor of the lake.

From these sections it is clear that the ancient loch of Holyrood had originally a depth of between 30 and 40 feet at places, and that after several vicissitudes in climate it became silted up with material brought down by streams from the adjacent high ground. One of these brooks probably ran northwards along the hollow encircling the base of Salisbury Crags, along the line of the Queen's Drive, and a second entered from the west, carrying down the drainage of the valley between the Castlehill and the Calton, afterwards partially occupied by the Nor' Loch. As the lake shallowed, the fauna which flourished in the deeper water was choked out, and the area became overgrown with peat, only a few pools remaining to mark the place in historic times. The peat was full of twigs of birch, hazel, and other trees, which no doubt at one time formed part of the thick forest of Drumsheugh, whose gnarled oaks and sombre pines once cast their dark shadows across the bosom of this ancient lake.

6. Lochend Loch.

Of all the old Edinburgh lakes this little one seems to have undergone least change since the earliest times. It has no streams of any consequence for feeders, and hence has not become silted up. The water seems to be derived chiefly from springs, and as such is clear and free from sediment. The outlet to the west is small, and although the level of the overflow may have been somewhat lowered, there is not much evidence of any considerable shrinkage in the area.

7. Duddingstone Loch.

Although still the largest of the Edinburgh lakes, Duddingstone Loch covers but a fraction of its original area, and the merest tyro in field geology can see that about half of the present lake has recently degenerated into a reedy marsh, which will at no distant date gradually become dried up and disappear in the ordinary course of nature. The level of the

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water is but a few feet below the 150-feet contour line, and by following this line we can approximately trace out the ancient margin. As all skaters know, this loch is supplied principally by springs rising at the foot of the Hangman's Rock and the Girnal Crag, and the outlet passes south-eastwards into the Braid Burn near the railway station. The ancient lake probably extended over the whole of the flat depression between Duddingstone and Inch House; and although it is not certain that the slight knoll on which the old mansion-house stands was actually ever a complete island, as its name would imply, yet it may have been near enough the water to have in Celtic times been described by that common epithet.

The ancient loch was supplied partly by the existing springs and partly by the waters of the Braid Burn and its tributary the Pow Burn, which join near Peffermill, and probably at first entered by separate mouths into the basin. These streams, in their original state before modern improvements had altered their courses and the character of the surrounding land, were no doubt subject to powerful spates. Large quantities of alluvium were swept down on these occasions from the high ground of the Braids and Blackford Hill, and deposited, where the current slackened, in the form of a flat delta at this end of the lake. Gradually the alluvial fan pushed back the water and spread over the greater part of the shallow basin, until at last this part of the depression was completely silted up, and the streams, uniting into one, parted company with their shrunken old friend the loch, and, passing it, left it to be maintained entirely by the springs and rills from the adjacent slopes of Arthur's Seat. The southern part of the basin, whose total length apparently exceeded a mile, at the end of the Ice age, was probably shallow, and the silting-up was a comparatively rapid process, so that many centuries must have elapsed since the loch shrunk nearly to its present area. The deepening of the outlet by artificial means has no doubt helped further to reduce it within recent times.

On the smaller pools or ponds in the district to which I have already alluded, the map shows two along the course of the Jordan Burn. One of these, which occupies the hollow south of Morningside Asylum, is represented by a well-marked series of lacustrine beds, exposed when the Suburban Railway cutting was made. Under the surface vegetable soil, which had a thickness of two feet, a bed of peat three feet thick was found resting on shell marl two to three feet in depth. The peat and marl extended along the cutting for nearly half-a-mile westwards from the Morningside station to the point where the rock cutting begins at Myreside.

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Another lakelet with a well-marked bed of marl existed at the foot of Blackford Hill, in the course of the Pow Burn. Canonmills Loch, again, was a pool connected with the Water of Leith, which occupied the hollow overlooked by the Royal Crescent. It is referred to in old maps and descriptions of Edinburgh, and was not completely removed till 1865, during the construction of the Royal Gymnasium.

The old tarn at Hailes Quarry, near Colinton, which is not shown on the map, but possesses some interesting features, has been lately studied in detail by Mr Bennie, who has supplied me with the following notes regarding it. The section recently exposed at the N.E. corner of the quarry was as follows:—

5. Vegetable soil resting on ochreous sand with no organic remains.
4. Beds of fine silt, coarse sand and gravel, with numerous seeds of *Potamogeton*, hazel-nuts, acorns, bark, twigs, branches, and even small trunks of trees.
3. Muddy silt 1 foot, with rootlets and layers of Arctic plant leaves and frequent remains of *Apus glacialis*, a freshwater crustacean confined now to Greenland and Spitzbergen.
2. Layer of stones 1 foot, evidently washed out of the boulder clay.
1. Boulder clay or till covering the rock, from 2 to 14 feet deep.

This section, which has yielded the first recognised specimens of Arctic plants, shows that the lake came into existence as soon as the ice sheet had left the ground clear, and was originally tenanted by a flora and fauna confined now to a much colder habitat. It was afterwards filled up by currents which swept in fragments of the adjacent forests and alluvium from the higher ground. The "wash out" and other points of interest in this section have been described at meetings of the Edinburgh Geological Society at various times (see vol. i. page 8). On 5th January 1865, Mr Thomas Marshall read a paper here "On the Tibia of the Extinct Caledonian Ox, found 5 feet below the surface in peat overlying sandstone in Hailes Quarry" (see *Geol. Mag.* vol. ii. page 76). This must have been in bed 3 of the above section, and recently Mr Marshall's relatives, who still possessed the specimen, generously presented it to the Anatomical Museum at the University, where it may now be seen. The Arctic plant deposit which Mr Bennie found in the Corstorphine lake bed was identical in its contents with that of Hailes, but was much larger, and was overlaid by a thick bed of marl and plants of later origin. Part of a magnificent antler of a red deer was also found embedded in the silt above the plant bed in one of the recent drainage excavations already referred to.

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XXXV.—*On Sections Exposed on the Line of the Barnton Railway.* By JOHN HENDERSON.

(Read 19th January 1893.)

THE Barnton Railway branches off from the Caledonian line to Leith, a short distance to the west of Craigleith Quarry. The line passes in a north-west direction to the east end of the village of Davidson's Mains, then, with a bend to the west, passes along the back of that village on its north side, and into the Barnton estate, where it crosses the northern end of Corstorphine Hill, and it is here that the principal section has been exposed.

The first sections exposed on this line of railway lie to the north-west of Craigleith Quarry, between that quarry and Davidson's Mains. The beds here exposed consist mainly of the blue-black till or boulder clay so common to the district. The enclosed boulders, of which there are great numbers, are principally of Corstorphine greenstone, some of them finely striated; along with these are blocks of sandstone and occasionally small boulders of limestone, fragments of felstone, porphyry, bits of shale, &c. The only other noticeable feature that I observed here was a long line of boulders at the north end of the principal cutting. They lay about six feet below the surface, and projected beyond the sloping face of the cutting on both sides. They rested on boulder-clay which contained patches of sands and gravels here and there on which some of the boulders rested. Beneath this line of boulders very few others could be detected in this part of the cutting. I have noticed boulders lying in lines in other sections of boulder-clay in this district, and in some instances much deeper from the surface than the boulders in this section.

The most interesting section exposed on this line of railway lies to the west of the village of Davidson's Mains, where the line enters the estate of Barnton after crossing the road that leads down to Cramond village. Here a cutting has been made exposing beds of sandstone, shale, and greenstone to the extent of about four hundred yards. At the east end of the cutting beds of grey and yellowish sandstone are exposed to the extent of about seventy yards, dipping west at 30°. These are followed by dark shales between twenty and thirty yards in

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extent. Then comes a bed of whinstone about eight yards wide. This is in all likelihood an intrusive bed, but the junction with the shales, which lie on each side of it, cannot readily be made out. Beyond this comes a set of black and grey shales fifty yards in extent, having a dip to the west at 20°. Then follows a bed of intrusive greenstone ten yards wide, dipping conformably with the shales, which are hardened by contact. Above this lie some beds of highly indurated shales six yards wide. Then comes an immense mass of greenstone extending for two hundred yards along the line. This greenstone seems to lie on the shale at its junction, and to dip conformably with it; and, in fact, the greenstone in many places in this section has an apparent bedding and dip to the west. There are other features in this section which I will notice further on. At present I wish to call attention to the position the beds in this section hold in the lower carboniferous system of the district.

In the session of 1870 I read a paper, on January 20, before this Society on a section exposed during the opening of a pavement quarry on the eastern face of Corstorphine Hill, a little to the south of the Queensferry Road. The beds there exposed, which were quarried for pavement, I held to be the Wardie shales, with a dip to the west passing under the greenstone of the hill, which lies in great thickness above them. The opinions I then expressed regarding the arrangement and superposition of the rocks to the west of Edinburgh, I knew, differed widely from those held by well-known authorities on our local geology. Since then I am more confirmed in these opinions, and I adopt them in explaining this section on the railway.

Although the great mass of igneous rock that forms the long irregular summit of Corstorphine Hill appears to dip conformably with the sedimentary beds beneath, yet it rests on different beds along its outcrop. At the back of Craigcrook Castle, the greenstone rests on sandstones of the Craigleith series. At the pavement quarry, about half-a-mile farther north, it rests on shales of the Wardie series. Between this and the railway cutting it rests, in all likelihood, judging by the direction of the strike of these beds, on the sandstones first exposed in the cutting. Then, again, in this section it rests on shales higher than those of the Wardie series. In fact, the base of the greenstone in its extension northwards is evidently in contact with higher sedimentary beds, as if cutting its way upwards through the strata. The trap can be traced in the parks of Barnton northwards for about a quarter of a mile from the railway cutting, and a short distance to the north-west of where the last exposure is to be seen, a sandstone quarry has been opened. This sandstone, from its position, seems to rest on the back of

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the greenstone, as the sandstone beds have apparently been faulted down to the west, with a westerly dip of about 30°, leaving a portion next the trap broken and faulted. This also dips west, but at a very high angle, as though some intrusive body had forced its way upwards from beneath.

The extension of the greenstone farther north cannot readily be traced. There are several beds of intrusive trap on the shore in the neighbourhood of Cramond, and the one that agrees most in character with the eruptive rock of Corstorphine Hill is a bed that crops out on the shore about six hundred yards east from the mouth of the river Almond. If this be a continuation of the trap of Corstorphine Hill, then it is in contact with still higher beds of the lower carboniferous series in its extension to the sea coast. But apart from the stratigraphical position of the rocks exposed along the railway, the section itself presents features that must be of interest to the geologist. About sixty yards west from where the greenstone is in contact with the shale a vein or thin dyke cuts the trap and passes obliquely from below to the surface. This dyke is clearly separate from the trap, and comes away in cube-like blocks, as it is traversed by cross joints which give it the appearance of steps in a ladder. It is of a highly crystalline texture quite different from the main mass of the rock, which in many places is so soft that it can be crushed into powder with the hand. The rock differs greatly in character in different parts of the mass, but I think the most interesting and most puzzling feature in this section is its weathered condition. At the middle and eastern portion of the section the trap and shales are covered with a reddish brown sand, which, upon closer inspection, proves to be weathered trap. In depth it ranges from four feet at the west end to eight or ten feet at the east, while the rock below it shows traces of weathering as far down as the bottom of the cutting. But the weathered trap is not confined to the top of that rock itself, but extends eastward over the broken ends of the shales for about one hundred yards, to the outcrop of the sandstones, whose broken ends are covered with dark boulder clay. Near the junction of the sandstone and shales, on the west side of the bridge that carries the roadway over the railway to Barnton House, a vertical section of this weathered rock is to be seen. This section at the bridge has the appearance of a bed of brown sand with fragments of black shale spread through its base, but upon closer inspection can be seen the irregular outlines of blocks of trap in so weathered a condition that it is possible to scoop them out with the hand. They are evidently pieces of trap transported from the beds lying to the west and weathered where they now

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lie; and this, in all likelihood, is the origin of all the weathered beds in the section. The same features can be seen at the old pavement quarry on the eastern face of Corstorphine Hill, half-a-mile farther south. When the boulder-clay which was covering the trap was cleared away, the western face of the trap was found to show beautifully rounded hummocks finely striated, with no indications of weathering; while in the park on the south side of the railway, to the west of the greenstone ridge, can be seen as fine a series of rounded hummocks as are to be found anywhere in the county. Not only so, but some of them show distinct striations, and those rocks have in all likelihood stood there without covering and exposed to the weather since the ice-sheet left the district. How, then, can we account for the different conditions under which this trap weathers? In dealing with the glacial phenomena of the district, we find certain anomalous conditions in connection with Corstorphine Hill that we don't find anywhere else. For instance, instead of an abrupt craig facing the west, and a long ridge stretching away eastward, as is usual where trap and other hard rocks crop up in the district showing the well-known features of craig and tail, we have in the middle portion of the hill a gradual slope facing the west, and an abrupt cliff and steep slope facing the east, and at the bottom of that slope a nearly silted up loch known as the Marl Pits, referred to in Mr Cadell's paper in this volume as the site of one of the ancient lakes of Edinburgh.

The depth of this valley from the summit of the hill is upwards of three hundred feet. The question naturally arises, By what process was this valley and the loch basin formed? Was it the work of the ice-sheet during the glacial period? If so, how can we account for the rugged and broken surfaces of the rocks on the east side of the hill, and the deposits of weathered trap as exposed in this section on the railway and other portions of the hill? To these questions an answer has yet to be found.

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XXXVI.—*Note on the Minerals observed in the Railway Cutting at Barnton, near Edinburgh.* By J. G. Goodchild, H.M. Geol. Survey, F.G.S., F.Z.S.

(Read 4th May 1893.)

In the course of one of the Saturday evening excursions of the Heriot-Watt Geology Class in the spring of the present year (1893), the rocks now being exposed in the new railway cuttings to the west of Davidson's Mains were studied in some detail. The sedimentary rocks outcropping there are of Lower Carboniferous age, and appear to correspond in geological position with the highest beds of the Granton Sandstone, together with the lower part of the overlying Wardie Shales. Their prevailing dip is westward. At this point these rocks have been invaded by a sheet of igneous rock forming part of the intrude of the Corstorphine Hill, and whose bounding surface nearly follows the bedding of the sedimentary rocks. In its outer parts the rock at Barnton consists of a holocrystalline aggregate of plagioclase felspar, and pyroxene, combined in about equal proportions; together with ilmenite, a serpentinous mineral, and some leucoxene. It shows well-marked ophitic structure, and is, therefore a dolerite.

The central portion of the mass is different in both structure and composition. It consists of a holocrystalline compound of olivine (and of serpentine representing that mineral), pyroxene, brown mica, and an ore of iron. Felspar occurs in either small proportion or is absent entirely. The structure of the aggregate is granitic; this part of the rock, therefore, is a picrite.

Here and there the picrite itself is traversed by segregation-veins, which are, as usual, of a more acid composition than the mass, and which agree closely in character with the dolerite enclosing the picrite.

The ultrabasic rock weathers very rapidly, and occurs as a loose, friable mass, decomposed to a depth of many feet below the surface.

Some very interesting contact-metamorphism is exhibited by the shales where they adjoin the intrusive rock. These are indurated into compact, flinty beds to a distance of two or three feet from the plane of contact; and in places the change induced by the heated mass has taken the form of a complete re-arrangement of the argillaceous matter into an aggregation of small

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spheroids, which bear a close superficial resemblance to a coarse oolite or pisolite.[1]

Along the joints and other divisional planes traversing the igneous rock, and especially along those within the more basic portion, occurs a number of interesting minerals, chiefly zeolites and other decomposition-products arising from the mass. The most noteworthy occurred well crystallised, in the form of thin vein-like aggregations traversing the picrite. Suspecting the mineral to be datolite, a hydrous silicate of calcium and boron, I submitted a specimen of it to Professor Heddle, who at once confirmed the identification, and shortly afterwards paid a visit to the locality with me. On this occasion Professor Heddle detected some other minerals, which, together with those found by the students of the Heriot-Watt Geology Class, brings the number of species (including the rock-forming minerals) up to more than twenty. Since the date of Professor Heddle's visit several members of the class have repeatedly collected in the cutting, and have secured several fine specimens of minerals, some of which they have presented to the collection of Scottish minerals in the Edinburgh Museum of Science and Art.

The list of minerals observed in the cutting is as follows :—

Augite ; a rhombic pyroxene ; a uralitised form of pyroxene ;[2] labradorite ; albite ; olivine ; biotite ; ilmenite ; leucoxene ; chromite ;[3] pyrites ; limonite ; serpentine ; pilolite ; saponite ; calcite ; aragonite ; opal ; prehnite ; analcime ; pectolite ; natrolite ; datolite.

To these may be added the quartz and muscovite occurring in the sandstones, and also the garnets and the other contact minerals which a microscopic examination will probably bring to light in the altered shales.

[1] An identical structure is developed in the shales of the Inferior Oolites at the Shiant Isles, where they are invaded by the great basic intrude, or so-called "gabbro" of that part.

[2] Identified by Mr John A. Johnstone.

[3] Inferred by Professor Heddle from its decomposition-products.

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XXXVII.—*"Notes on a Shell Mound" at Tongue Ferry, Sutherland.* By B. N. PEACH and J. HORNE, of the Geological Survey of Scotland.

(Read 16th March 1893.)

IT will be readily admitted by those who have been following the general results of archæological research, that the investigation of those shell mounds left by the hand of man in Scotland has not led to such important conclusions as the study of similar deposits in Denmark. Doubtless this may be partly accounted for by the fact that these accumulations occur on a much larger scale in Denmark, and are more richly charged with relics of man's handiwork. The evidence obtained points to the conclusion that the Danish shell mounds or "kitchen middens" belong to some part of the neolithic or new stone age. But if we ransack the Transactions of the Antiquarian Society of Scotland to see what has been done in connection with this subject in our own country, the results are not quite so satisfactory. An unbiassed reader would be apt to infer that few of the shell mounds date back to neolithic time. In some cases the evidence in support of this contention can hardly be said to be conclusive. Indeed, one is almost tempted to put the question: Is there in the northern Highlands a shell mound of undoubted neolithic age? If so, where is it, and what is the evidence in proof of it?

This line of research was suggested to us by a recent examination of the contents of an ancient shell mound on the western shore of the Kyle of Tongue, not far to the north of the ferry house. In the course of our official duties in that region, we made a collection of the more interesting relics associated with this mound. Prominent among these are two stone implements in good preservation. When these implements, together with the fragments of pottery and the organic remains, were submitted to Dr Anderson for his inspection, he wrote, that he did not know at the moment of any other undoubted instance of a stone celt having been found in a "kitchen midden" or shell heap in Scotland. But for this fact it is probable that this shell mound, "with its ancient and fish-like smell," would not have been recorded so far as we are concerned.

Before calling attention to the relics we obtained, it may not be uninteresting to the members of this Society if we give a

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brief summary of the researches of Scottish investigators among these memorials of man.

In the Highland area we find that various observers have more or less minutely described shell mounds along the margin of the sea. One of the earliest notices of these accumulations on the shores of the Moray Firth, is by the Rev. Dr Gordon of Birnie, who directed special attention to the mound on Brigzes farm near the old margin of the Loch of Spynie. This mound, now separated into two parts, measures 80 by 30 yards for the larger, and 26 by 30 yards for the smaller portion. He notes the occurrence of the periwinkle, which is the most abundant shell, the oyster, the mussel, and the cockle, and suggests that at the time when the mound was accumulated, the bed of Loch Spynie was an arm of the sea. On that extensive flat, wherever any opening has been made, oysters are met with, seemingly on the spots where they lived. But he adds that the oyster has now passed away from our coast, save in some sheltered nooks of the Firth as at Cromarty and Avoch.

There is one shell, occupying the fifth place in point of numbers, in the mound, to which Dr Gordon directs special attention, viz., *Tapes decussata*. He says that it is not known to exist now in the Moray Firth, and the most northerly locality where it is now found alive is the coast of Caernarvonshire. While the other species that are now extinct on our shores are withdrawing to the north, and are found alive only towards the Arctic Circle, this species, once frequent, has withdrawn in the opposite direction to a warmer latitude.

This well-known observer also called attention to a shell mound on the west side of the Burghead railway, about a mile from the terminus, containing the usual species of edible shells, with a number of bones of animals, broken longitudinally to reach the marrow.

The description published by Dr Gordon about the year 1862, at once attracted the attention of Sir John Lubbock, who paid a visit to the shores of the Moray Firth, for the purpose of studying the mounds on the spot. Dr Gordon showed him all the "kitchen middens" then known to him, and the remains of the old lake dwelling in the Loch of the Clans, discovered by the late Dr Grigor. This examination led to the publication of an important paper by Sir John Lubbock on "A Visit to the Ancient Shell Mounds of Scotland," published in the *Natural History Review*, in July 1863. The remarks made by this distinguished observer are specially interesting on account of his unbiassed opinions and wide experience.

In the mound on the west side of the Burghead railway, he determined the remains of bones belonging to the ox, sheep, and

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pig, but found no trace of pottery. On the opposite side of the railway, he found two other shell heaps containing bones of the ox, sheep, and pig, with a piece of stag's horn, but no pottery nor stone implements.

After a brief reference to various shell mounds between Burghead and the Findhorn, the author describes the contents of the mound on Brigzes Farm, on the margin of the old Loch of Spynie. He spent four hours in the examination of this mound with the assistance of a labourer, and found not a single bone, not a trace of pottery, nor an implement of any kind. He suggests that the rarity of bones may be attributed to the insular position of the shell mound, but he was puzzled to account for the absence of pottery and implements. During his visit to one of the Danish shell mounds with Professor Steenstrup and Mr Burk, he obtained nine rude axes, besides flakes and other fragments of flint. To quote his own words, "I was therefore surprised, and, it must be confessed, a little disappointed, to find these Scotch shell mounds so poor. The difference may perhaps in part be accounted for by the absence of flint in the north of Scotland." How far this fact is an evidence that the shell mounds of the Moray Firth belong in a great measure to the metallic period, further researches will show. In the meantime it is an interesting fact that a bronze pin was found at this spot, and apparently in the shell mound itself, while on one of those between Burghead and the Findhorn, we found a small fragment of bronze, apparently a bit of a ring.

Sir John Lubbock states that this bronze pin resembles some of those found in Irish Crannoges, and on submitting it to Mr Franks he expressed the opinion that it was in use probably about A.D. 800 or 900. "It is, of course, evident (adds the author) that the presence of bronze establishes a great distinction between this shell mound and the much more ancient 'kitchen middens' of Denmark."

Reference is also made to shell mounds near the Ferry at Nigg, opposite Cromarty, and in a wood near Invergordon, which presented no features of special interest.

In the Transactions of the Antiquarian Society, vol. vii. p. 525 (1868), vol. viii. p. 63 (1869), two brief papers appeared by Mr Lawson Tait, Surgeon, Wakefield, Yorkshire, on "The shell mounds of Sutherland." At intervals along the coast, and in particular near the Little Ferry, the author observed many of these shell mounds; the chief varieties of shells being confined to the oyster, mussel, cockle, limpet, and periwinkle. He states that the shells of the oyster were of a very large kind, and although a small variety of this bivalve is now abundant on

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the west coast of Sutherland, he is not aware that the oyster occurs at all on the east coast. He also found fragments of chert, quartz, and flint, including a beautifully-worked but unfinished spear head of flint. He further adds that the shell mounds near Little Ferry correspond in every particular, save that of size, to the Danish "kitchen middens." This observation, were it true, would be of very great interest, but the author has not brought forward evidence to establish it.

In the interesting volume on the "Prehistoric Remains of Caithness," by Mr Laing and Professor Huxley, reference is made to several shell mounds, one of which, in Mr Laing's opinion, presents a close analogy to the Danish "kitchen middens." In the churchyard mound near Keiss Castle there is a mass of shells, about five feet deep and covering an area of several hundred square yards, resting on the natural soil, and overlain in turn by the foundation of a massive building, which has almost disappeared. In the author's opinion, the refuse heap cannot have accumulated about the building, but must have existed before it. The heap is composed mainly of periwinkle shells, but near the middle and lower parts of the mound chipped flints and rude stone and bone implements and pottery were found, including two bone arrow heads with eighteen skewers and pins of fragments of bone and horn. In the centre of the mass a human tooth was found, with a small portion of the jaw, together with wood ashes and charcoal. Animal bones were not abundant; the only stone implements were beach stones, probably used as hammers, and round pebbles or sling stones evidently selected from the beach. The pottery was in small fragments of the rudest description, and not distinguishable from the specimens the author had seen from the Danish "kitchen middens."

The last paper to which your attention will be directed is one by a distinguished Scottish glacialist, Mr Jamieson, Ellon, "On the Remains of the Stone Period in the Buchan District of Aberdeenshire," published in the Proceedings of the Antiquarian Society of Scotland in 1867. In this communication the author notes the occurrence of shell heaps at the mouth of the river Ythan, chiefly on the north side of the estuary, varying from thirty to ninety yards in length, and resting on mounds of blown sand. The most plentiful species is the mussel, which is associated with cockles and periwinkles, all of them large and full-grown specimens. Commingled with the shells are burnt stones and bits of charcoal. The author found a few teeth (referred by Sir William Turner to deer and oxen), and fragments of bone with an occasional flint, showing signs of having been burnt. Flint flakes and chips occur on the

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surface of some of these mounds, and more plentifully in the neighbourhood of them, so that there is every reason to suppose that the shell heaps were made by the chippers of the flints.

The shell mound on the western shore of the Kyle of Tongue occurs about seventy yards to the north of the Ferry House, and stands on a part of the 25-feet raised beach. A portion of the surface of this ancient terrace has been stripped of vegetation, and the shell heap is seen resting on sand and fine gravel, the length of the exposed portions not exceeding twenty yards.

The following is the list of shells gathered from the heap :—

1. *Ostrea edulis*, the oyster.
2. *Mya arenarea*, Gaper.
3. *Lutraria elliptica.*
4. *Artemis*, Sp.
5. *Solen ensis*, razor fish.
6. *Mytilus edulis*, mussel.
7. *Mytilus modiola*, horse mussel.
8. *Patella vulgata*, limpet.
9. *Littorina, littorea*, periwinkle.
10. *Purpura lapillus*, the dog whelk.
11. *Buccinum undatum*, the whelk.
12. *Cardium edule*, the cockle.
13. *Littorina rudis.*

Of these thirteen species the oyster occurs perhaps in greatest abundance and of a large size, which is all the more interesting from the fact that it has now disappeared from the Kyle. At first we were inclined to believe that the abundance of the oyster might be partly accounted for by supposing that a submergence of the land to the extent of twenty-five feet would produce more marine conditions and render the water less brackish. But the disappearance of the oyster in recent years on many parts of the Scotch coast may also be explained by the increased demand for this particular shell-fish. These ancient mound-builders knew how to appreciate a good thing, and so do their successors of the present day! In fact, the demand is so great that it threatens to exterminate them altogether.

It is obvious, therefore, that it is quite unsafe to base any argument on the disappearance of the oyster as indicating a change of marine conditions in the Kyle since the accumulation of the mound.

Next in order among the relics we noted a stone celt in good preservation. It measures about three inches in length, and about two inches along the cutting edge. The implement is not complete, however, having been fractured at one end before we found it. It is evidently formed of an igneous rock, pro-

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bably a dolerite. As yet we are not aware of any locality in the immediate neighbourhood from which this igneous rock could have been derived.

Near the stone celt, a stone implement was found which was evidently used as a hammer stone. It measures four-and-a-half inches in length and about three inches across, and has apparently been a stone picked from the beach, rounded by the action of the sea. This hammer stone is composed of fine-grained basalt, occurring in the form of thin intrusive dykes in the adjoining schists.

Next in order we gathered several fragments of coarse pottery which, judging from the rims, seem to have formed portions of five different pots. The pottery is extremely coarse, and, in the opinion of Dr Anderson, bears a close resemblance to the stone age and bronze age sepulchral pottery in appearance and texture. Indeed, this resemblance so impressed him that he asked whether there were no graves there, and if the sepulchral pottery and the domestic debris had not got mixed together. But there were no indications of graves; the fragments of pottery being scattered among the shell debris.

Several pieces of long bones, evidently split for marrow, were obtained, but these have not been identified. A quartzite flake occurred among the debris. The nearest locality where this particular quartzite can be got is at Heilim or Hope Ferry.

Finally, we noted numerous burnt stones and a piece of slag produced by the heat of the fires.

Viewing the relics from this "kitchen-midden" and the evidence which they afford, it seems to us that there is but one new fact, if it is really new regarding our Scottish shell-mounds, and that is the occurrence of the stone celt. Taken in connection with the hammer stone and the pottery on the one hand, and the absence of bronze implements on the other hand, the evidence is in favour of the neolithic age of this particular mound. But it must be confessed that the evidence is by no means overwhelming. The record of this stone celt may however induce members of the Society to pay increased attention to these savoury memorials of the past.

NOTE.—The collection of shells, implements, and pottery, is now deposited in the Antiquarian Museum in Edinburgh.

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XXXVIII.—*On the Occurrence of Shelly Boulder Clay in North Ronaldshay, Orkney.* By B. N. PEACH and J. HORNE, of H.M. Geological Survey.

(Read 16th March 1893.)

THE investigations which we carried on for four years in Shetland, Orkney, and Caithness during our annual holidays regarding the extension of the ice in the North Sea during the glacial period, have since been supplemented by certain interesting observations by the late Dr Traill in the island of North Ronaldshay. To the latter we desire to call attention in order to show their bearing on the development of the Scandinavian and Scottish ice-sheets during the climax of glacial cold.

The results of our own researches, which were published in the Quarterly Journal of the Geological Society and in the Transactions of the Royal Physical Society, Edinburgh, point to the conclusion that during the period of extreme glaciation, Shetland, Orkney, and a large part of Caithness were glaciated by ice moving *from the North Sea towards the Atlantic.* This conclusion was sustained alike by the direction of the ice-markings, the position of the *rockes moutonnées*, the distribution of the boulder clay, and the dispersal of the stones in that deposit.

In Shetland, where the lithological characters of the rocks are somewhat varied, the glacialist can reason definitely as to the direction of the ice movement from the distribution of the stones in the boulder clay. Along the western seaboard of Unst striated blocks of serpentine and gabbro are found in this deposit which must have been transported from the eastern side of the island; while on the western shore of the mainland, between Scalloway and Fitful Head, blocks of Old Red Sandstone grits and flags are met with in the boulder clay, which must have been carried across the water-shed. No shelly boulder clay was obtained by us in Shetland, nor any fragments of Secondary rocks. Possibly some of the blocks of crystalline schists and gneiss in the glacial deposits may be foreign to the islands, but so far as we could judge they might all be of local origin.

In Orkney, however, we found certain striking facts indicating that the ice which glaciated that group of islands must have come from Scotland. With the exception of a very small area

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near Stromness, these isles are composed of Old Red Sandstone strata belonging chiefly to the horizon of the Caithness flagstones. Notwithstanding this fact, it is worthy of note that in various boulder clay sections throughout the islands we observed numerous fragments of Secondary rocks, including chalk, chalk flints, oolitic limestone, calcareous breccia, fossil wood (*Peuce Lindleyana*). These were associated with blocks of dark calcareous shale charged with well-preserved specimens of *Lepidostrobus*, resembling some of the thin limestone bands in the Cement-stone series of Central Scotland. Regarding the Secondary rocks, Professor Judd stated that two specimens of the calcareous breccia from the boulder clay in Odin Bay very closely resemble parts of the Upper Oolites in Sutherland, and two other blocks are probably from the same locality. The presence of various schistose rock foreign to the Orcadian group and bearing a close resemblance to those in the north-east of Scotland, furnishes similar testimony regarding the direction of the ice movement.

No less interesting was the discovery of numerous fragments of shells in the ground-moraine, presenting in some cases smoothed edges and striated surfaces like the stones in that deposit. Indeed, with the exception of the difference in colour, the Orcadian shelly boulder clay is but the counterpart of the similar deposit in Caithness, which has become familiar to geologists through the researches of Dr Jamieson, Mr C. W. Peach, Dr Anderson, Mr Dick, and others.

Our lamented friend Dr Croll threw out the suggestion that the Caithness boulder clay was formed by land ice moving in a north-west direction towards the Atlantic. He was led to this conclusion partly by the fact that many of the blocks of Secondary rocks resemble strata of this age on the east coast of Sutherland, and partly by the conviction that the depth of water in the North Sea would not be sufficient to float the Scottish and Scandinavian ice sheets. From the estimates of the thickness of the respective ice sheets, he inferred that they coalesced on the floor of the German Ocean, and that a large portion of the combined ice-field moved north-westwards towards the Atlantic, while another portion moved southwards towards the English coast. Many years before Dr Croll advanced these opinions the suggestion had been thrown out by Agassiz that the North Sea had been occupied by land ice during the glacial period, which, like many of his original speculations regarding glacial phenomena was at first received with little favour by geologists in this country. We understand that the early speculations of Agassiz regarding the extension of the ice in the North Sea were unknown to Dr Croll, so that the same conclusion had been reached independently by both these investigators.

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Apart from our own researches in Shetland, Orkney, and Caithness, it is interesting to observe how the detailed examination of glacial phenomena both in Britain and on the Continent completely corroborates this generalisation. Our president, Professor James Geikie, in a paper contributed recently to the Royal Society of Edinburgh on "The Glacial Succession in Europe," has given an admirable summary of the evidence relating to the extension of the British and Scandinavian ice-sheets. The researches of our colleagues, Mr Clement Reid and Mr Lamplugh, on the glacial deposits of the eastern counties of England, furnish a large body of evidence pointing to the conclusion that these ice sheets coalesced on the floor of the North Sea. In a remarkable paper on "The Drifts of Flamborough Head," by Mr Lamplugh, published in the Quarterly Journal of the Geological Society for 1891, he states that the glaciation of that region was effected by land ice of extraneous origin, which moved coastwise down the North Sea, and did not overflow the greater part of the Yorkshire Wolds. He further states that neither the boulder clay nor the intermediate gravels are of marine origin, the shells which sometimes occur in them being derivative. His interpretation of the glacial succession in that neighbourhood is different from that hitherto accepted, but he strongly advocates the land ice origin of the boulder clays. He maintains that the great *mer de glace* filled the North Sea basin in that latitude from the commencement of the glaciation to its close, and hence there is no clear evidence on Flamborough Head of a mild inter-glacial period, but only of extensive fluctuations of the margin of the ice.

During our traverses in Orkney we had no opportunity of visiting North Ronaldshay, which is situated at the extreme north-east corner of the Orcadian group. This was to some extent a disappointment at the time, because we were anxious to ascertain the northern limit of the Orcadian type of shelly boulder clay. Fortunately the evidence has been supplied by the observations of the late Dr Traill. Having read our paper on "The Glaciation of the Orkney Isles," he made a careful examination of several sections with gratifying results. From time to time he sent us a large collection of stones from the deposit for determination, which prove beyond all doubt the presence of Scottish rocks in the boulder clay. Like the other isles, North Ronaldshay is composed of Old Red Sandstone strata of the Caithness flagstone type. Near the middle of the broadest part of the island numerous trenches were dug, revealing at the surface from one to two feet of a black peaty loam. The underlying materials consist of stiff red stony clay, similar in character to the sections we had described in the other isles. The following

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table gives the result of our examination of the stones from this deposit :—

	No. of specimens.		No. of specimens.
Granite	17	Vein quartz	3
Hornblendic granite	3	Jasper	1
Syenite	1	Marble	6
Granitoid rock	4	Old Red Sandstone	17
Felsite	5	Old Red Conglomerate	1
Hornblende rock	3	Old Red flagstones, some with plant remains	4
Gabbro and Epidiorite	5	Old Red cornstone	1
Hornblende schist	4	Volcanic ash, like tuff from the Ochils	1
Gneiss	10	Chalk flints	6
Mica schist	1	Numerous small fragments of chalk.	
Quartz schist	4		
Quartzite	22		
Crystalline grit	9		

It must be borne in mind that these numbers give no indication of the relative proportion of the various rocks in the boulder clay. It is probable, if not certain, that the great majority of the included blocks have been derived from Old Red Sandstone strata. But a glance at the list shows plainly enough that the assemblage of stones in the boulder clay of North Ronaldshay is similar to that in the other members of the Orcadian group. It is interesting to note also that many of them closely resemble rocks found *in situ* round the basin of the Moray Firth, or in the adjoining tracts. For example, the specimens of gabbro, epidiorite, and hornblende schist, are extremely like the rocks of this nature stretching from Portsoy south-westwards to the high grounds of Aberdeenshire. The marble may also have been derived from the same region, while the quartzites, quartz-schists, and mica-schists, very closely resemble the strata of these types extending from Banffshire to Perthshire. The specimens of chalk and chalk flints are like blocks of the same materials met with in the drift of Banffshire and Aberdeenshire. In short, if we except the stones which are undoubtedly of local origin, the remainder may have been derived from the areas crossed by the ice which radiated from the eastern Highlands into the basin of the Moray Firth, or towards the North Sea by Kincardineshire and Perthshire.

Equally interesting is the occurrence of numerous fragments of marine shells, in the boulder clay, presenting smoothed and striated surfaces like the stones in the deposit. From the fragmentary character of the materials, the determination of the shells is surrounded with difficulty. By far the most abundant form is *Cyprina Islandica*, but the following genera are also

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represented, *Astarte*, *Mytilus*, and *Dentalium*. A glance at those glaciated shell fragments leaves no room for doubt that they are derivative. Their condition is totally different from that of the organic remains in the shelly clays of the Firth of Clyde. Indeed, there is no escape from the conclusion that the shelly boulder clay of North Ronaldshay is a product of land ice.

These observations of the late Dr Traill are invested with considerable interest, because they clearly show that the Scottish ice sheet must have advanced north-westwards so as to override the whole of the Orcadian group. An interesting question still awaits solution, whether the drift of the Fair Isle, which lies about midway between Orkney and Shetland, presents features similar to those we have just described.

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XXXIX.—*The Ejected Blocks of Monte Somma.* By H. J. JOHNSTON-LAVIS, M.D., F.G.S., &c.; Professor of Vulcanology, University of Naples. *Foreign Corresponding Fellow.*

PART I.—STRATIFIED LIMESTONES.

THE ejected blocks of Vesuvius, or, more properly speaking, Monte Somma, have been renowned for over a century as affording a large number of mineral species. So attractive were they that they are included in the catalogues of the productions of this volcano by Galiani in 1772, "Galiani Catalogo delle materie appartenenti al Vesuvio," Lond., 1772, and by Sir William Hamilton, "Campi Phlegrae," and Gioieni in 1789, "Gioieni. Saggio di litologia Vesuviana," Napoli, 1789.

Hamilton, besides giving figures of some of them in his book, made a rather extensive collection, now exhibited in the British Museum. Many species of minerals were first described from this source, whilst those blocks and their contents have occupied the attention of Thomson, Monticelli, Covelli, and Tenore. Professor A. Scacchi may be said to have devoted his life to the study of their mineral contents, together with that of others produced during the modern eruptive action of this volcano. Scacchi, in a catalogue published not long since,[1] gives fifty-two as the number of mineral species (not varieties) occurring in the ejected blocks of Monte Somma.

It is, therefore, evident that a careful examination of these rock masses would be quite justifiable for the sake of studying the conditions under which so large a number of minerals occur, and of the relation they bear to each other. But beyond this, they have a much higher claim on our attention from a geological or vulcanological point of view. In the first place, no other volcano is yet known to possess, in so great abundance, so large a variety of ejected blocks; secondly, they constitute a collection of different rock-masses associated together, such as occurs in no other known locality of an equal area.

Numerous papers treating of the minerals derived from this source we owe to the investigations of Vom Rath, and, lastly, a recent memoir by Herr Bruno Mierisch, "Die Auswurfsblöcke des Monte Somma, Tschermak's Mineralog, und Petrograph,

[1] "Atti. R. Ist. d'Incoraggiamento di Napoli," 1888, 4a Ser., Vol. I., pp. 57, Pl. 4.—"Jahrb. f. Mineral." B. II., 2a H., Stuttgart, 1888, pp. 123-141.

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Mittheillungen," pp. 113-189, Vienna, 1886, is an important addition to our knowledge of the microscopic structure of these interesting minerals. I was unacquainted with this memoir when the present paper was written about six years since, and consequently a revision was necessary which pressure of other work has retarded. Mierisch's and my own investigations, in so far as they cover the same ground, lead to very similar conclusions; but that gentleman has devoted himself in a very skilful manner to the elucidation of crystal structure, whilst my own researches have been along the line of rock structure. In other words, his researches are mineralogical, whilst mine are geological. Over and above that, his investigations were entirely limited to the drusy limestones and their contents, whilst my present paper refers to the stratified limestones and their immediate derivatives. Lastly, Herr Mierisch's observations were upon only eighty specimens, and he had apparently not studied them in the field, a not unimportant condition when we remember that those specimens met with in museums are always chosen for the beauty of their enclosures of free crystals, regardless of the matrix and the associations together of different rock types in the same block.

Having been brought constantly amongst these blocks, whilst constructing the large geological map of Vesuvius and Monte Somma, I have been able to collect nearly seven hundred specimens, and to study in much detail their mode of occurrence, associations, size, and other characters. From these facts, it would impress any one with the very large number of rocks represented, many of which are so far undescribed. The most important fact of all is the graduation from a perfectly unaltered limestone containing recognisable fossils, through various stages of change, to a considerable number of true metamorphic rocks that, in their turn, shade into many both known and unknown kinds of igneous rocks, which more and more approach the different modifications of the normal cooled magma proper to this volcano.

If a geologist attempts to study the relationship of a volcanic neck or duct to the surrounding rocks, even in such districts as Schemnitz or the Tyrol, he meets with two almost insurmountable difficulties—the first is that such a study can only take place at one horizon, so that he knows nothing lower than what is shown in the deepest gorge bottom, or nothing above what is displayed on the highest hill top. In the next place, by the time a volcanic neck has become exposed by denudation, all the rocks have undergone such marked changes as foliation, serpentinisation, schillerisation, hydration, weathering, &c., that the former structure has become so masked by the secondary

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metamorphoses and alterations that deductions cannot safely be drawn from such material.

With ejected blocks from a still active volcano it is quite otherwise. These blocks are specimens torn off from the sides of the volcanic neck and canal at various depths, so that the geologist is able to study the rocks in a vertical instead of a horizontal extension; and beyond this, he is able to compare the lavas and scoria, gases, &c., produced at the surface with the specimens of the magma cooled at various depths and pressures during the suspended activity of the volcano.

But above all, he is able to carry on his investigations on rocks in which hardly any of the secondary alteration and metamorphism has occurred; and where this does occur to a slight extent he may learn lessons which were impossible if no graduated series was at hand.

Under such circumstances, I have very reluctantly undertaken a most difficult task, and it is therefore hoped that many defects may be overlooked and gaps filled up by more able hands than mine.

In the present communication the stratified limestones and their derivatives have been taken up on account of the lithological character of bedding serving as a guide and key to what occurs in the more massive varieties.

Classification of the Varieties of Ejected Blocks.—Amongst the rocks, perhaps the most remarkable, at first sight, are masses of plastic clays which show only from one to five millimetres of slight baking on their surface, and containing many fossil shells. These shells, as well as those enclosed in the next group, are nearly all of living species, although thoroughly mineralised. The clays pass into calcareous mudstones, often concretionary in structure, which may or may not be fossiliferous. True sandstone is rarely to be met with, and when it occurs, is not fossiliferous and of doubtful age, but is probably late tertiary, as are all the above-mentioned rocks. Amongst the specimens of my collection is one small piece of yellow quartzose grit looking very much like the Eocene "Macigno," but such material is very rarely to be met with here, whereas at Monte Vultura it is very common amongst the ejected blocks of that volcano. So far, I have not come across anything that indicates these later rocks having undergone metamorphism, which may be attributed to the fact that the magma could not reach so near the surface without opening a way to the atmosphere. Much rarer, but equally unaltered, we have a series of true limestone and dolomitic rocks containing much bituminous substance disseminated through them, which in many cases is collected more or less in different bands, so that the specimens

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often show a very fine stratified structure indicated by different shades of greyish brown to black, and often exhibiting miniature faulting. In other cases, the stratified nature of the rock is not apparent, and the structure may even be rather coarsely crystalline; but nearly always the stratification planes are marked by the presence of hydrocarbonaceous substances in greater or less proportions, except where broken by numerous white veins and eyes of pure calcite. There are also to be met with two principal varieties of calcareous conglomerate of small limestone pebbles. In one case these are imbedded in a calcareous matrix of moderately compact character, and are probably of the same age as the breccias that cover the stratified and crystalline limestones of the neighbourhood, whilst in the other the matrix is a soft, white, pulverulent (in fact, flour like) substance quite similar to what is formed at the present time in the neighbouring bay a few metres below sea-level. This rock I take to be very modern, perhaps more so than the clays, whilst the stratified crystalline, and probably compact conglomerate, are of cretaceous and post-pliocene age, respectively resembling in the most minute details of structure, &c., the appenine limestone of the district which constitutes the peninsula of Sorrento and dips beneath Vesuvius. Besides these, there are some specimens rarely met with of breccias and conglomerates of somewhat doubtful composition, which will be examined on a latter occasion.

One acquainted with the ejected blocks of Monte Somma cannot but be struck with the few metamorphosed examples of the tertiary rocks, whilst the limestones of cretaceous or earlier age afford an almost unlimited series of mineral aggregates. The physical changes in them have converted them into graphitic and into saccharoidal marbles, then oxides and aluminates have separated, and silicates have been introduced, so that many kinds of metamorphic rocks and minerals have resulted. They shade on the one hand into a series of ultra-basic and basic rocks, and these again to syenites with zircon, nepheline, and a peculiar rock with leucite may be met with, which in some cases forms a continuous series with certain porphyritic trachytes and pumices. On the other hand, the ultra-basic rocks graduate through a coarse series of crystalline masses that seem to bear the same relationship to the leucite-lavas as a gabbro does to a dolorite or basalt. Then we have a most interesting series of altered breccias, partly composed of limestone fragments and partly of igneous rocks, which have undergone re-metamorphism, so that the limestone fragments may have been simply melted into beads lining their original cavity, or may have become liquid and cooled, forming a minute solid

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lake, half filling the hollows, and in some cases with the crystals of wollastonite formed and floating on the surface, projecting as dead leaves from a frozen pond. Where the action has progressed still farther, the limestone has disappeared and olivine takes its place, or the original cavity may be lined with pyroxene, mica, or wollastonite, and more rarely garnet, sarcolite, nepheline, mizzonite, or idocrase. This metamorphism of this mixed breccia may have been accompanied by pressure, so that after becoming plastic, the limestone, as well as the igneous fragments, have been pressed out in long streaks.

Various tufas, grey compact trachyte, trachyte breccia, and other odd rocks are also to be met with. These I take to be the remnants of older volcanic deposits from other neighbouring vents which formed the most superficial layers of the Vesuvian subvolcanic platform. Besides these are a series of altered lavas, scorias, lapilli, &c., that often form the nucleus of volcanic bombs in eruptions where the cone is rent open. These are undoubtedly derived from the sides of that rent, in the vicinity of the chimney, crumbling away when no longer supported by the liquid column of lava. Professor Scacchi, who studied (Contribuzioni Mineralogiche per Servire alla Storia Vesuviana del Mese di Aprile 1872; Atti della R. Accad. d. Sc. Fis. e Mat. d. Napoli, Part I., Vol. V., Part II., Vol. VI.; Notizie Preliminari di alcune Specie Mineralogiche rinvenute nel Vesuvio dopo l'incendio di Aprile 1872; Renicont. d. R. Accad. d. Sc. Fis. e Mat. di Napoli, Oct. 1872; First Appendix to above in the *Rendiconto* of Dec. 1874, and Second Appendix in same of May 1875) the minerals of these of the eruption of 1872, supposed that they came from greater depths, but one who sees them in the field, and not simply in the hands of collectors, will soon be convinced to the contrary.

Mode of occurrence.—In my former paper on Vesuvius (Geology of Vesuvius and Monte Somma, Q.J.G.S., Vol. XL., p. 35) I adopted a classification of the ejectamenta, and more fully developed that classification in a paper specially devoted to the subject (On the fragmentary ejectamenta of Volcanoes, Proceed. Geol. Assoc., Vol. IX.). Reference is made to it here because it affords us a means of grouping ejected blocks. *Essential* ejectamenta are those products that issue in an incandescent condition, being the source of energy by which the other two groups are ejected. The *accessory* ejectamenta are those portions of cooled volcanic rocks composing the sides of the crater that are torn off, or, after crumbling in, are shot out by the *essential* ejectamenta. This group would also include old rocks of the volcano that had undergone more or less metamorphism by their proximity to the chimney. Thus, the

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bomb-contents of the 1872 lava would come under this head. In all probability most of the calcareo-igneous breccias belong to this group, being old ejectamenta crumbling down and falling into the apex of the tranquil crater, where, after being again covered by the re-growth of a cone, and being exposed to heat and pressure, they have been re-ejected by an explosive eruption. Possibly also, some of the gabbro-analogues may also come under this head, having cooled low down in the volcano and being torn off and ejected during a later explosion. Lastly, we have the *accidental* ejectamenta, called so, since their composition depends upon the chance of what rocks form the sub-volcanic platform. They are only ejected when the apex of the crater cavity formed by an explosive eruption extends below the platform of the volcano into the underlying rock, portions of which are torn off and shot out.

The distribution in time of the ejected blocks of Monte Somma and Vesuvius are extremely interesting. Thus *Phase II.*, or the long period, during which a cone some 7000 feet high was being built up by the chronic activity of the volcano, or by the ejection of lavas, scoria, dust, and other *essential* products, we do not meet associated with these any of the (with one or two rare exceptions) ejected blocks, for the very obvious reason that the lavas, &c., issued quietly from the top or sides of the cone, and only such as the 1872 type of bomb-contents could have been produced. During *Phase III.*, the summit of the great cone commenced to be truncated, and a crater excavated. Now, in the pumices of this first explosive phase, we meet with large numbers of accessory ejectamenta torn from the mass of the great cone, but in addition, large fragments of fossiliferous mudstones and clays are rather common, showing that the crater apex had reached down into the tertiary deposits beneath the volcano. We encounter a few bits of grey and white limestone, and sometimes a bit of *silicate*-charged limestone, but these are very rare and never larger than a nut, so that probably they were brought up by the violent purging of the volcanic duct. The next phase of the volcano, probably in direct sequence to the last, was a return to chronic activity, during which lava streams issued from rents in the side of the mountain, and no doubt the crater of explosion became more or less filled up by a new cone of eruption. This was followed by a comparatively long period of inactivity, after which occurred one of the most violent explosive eruptions of which there is evidence of having shaken the flanks of the ancient Somma.

It constitutes the PERIOD I., *Phase VI.*, and is represented by a mantle of fragmentary materials varying from one to five metres in thickness, covering the neighbouring district. These materials

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consist of the pumice or *essential* mixed with the *accessory* and *accidental* ejectamenta. This admixture takes place in different proportions at different horizons. In the lowest part, or the first ejected, almost all the bed is a mixture of pumice and leucitic lava fragments, indicating that the latter were derived from the sides of the crateral cavity, being excavated within the mass of the cone. At a little higher level fossiliferous mudstones and clays, with the limestone conglomerate with white matrix, indicating that the apex of the crateral cavity was extending down through the tertiary rocks forming the most superficial part of the platform. Soon fragments of altered limestone become very common, so that in some localities they form a large part of the ejectamenta, and a few bits of metamorphosed or silicated limestone may be met with. To quote the words in my former paper (*op. cit.* p. 67): "None of these erratics are absent from any part but they predominate at certain horizons." It is evident, therefore, that as the eruption progressed, the crateral apex was gradually lowered into the limestone subjacent to the tertiary clays and mudstones, but only reached that part that had been baked, stopping short of the still lower more highly metamorphosed materials.

PERIOD II., *Phase VI.*, was a small pumice eruption, apparently too weak to eject any *accessory*, and still less any *accidental*, ejectamenta. This was followed by PERIOD III., which seems to have chiefly been occupied in enlarging the upper part of the crater without extending it in depth, as *accessory* ejectamenta are common, whilst the *accidental* are almost absent. The pumice is very vitreous and spongy, and probably there was much expansion and escape of gas high up in the vent, so that only the crumbling edges of the crater were ejected.

In PERIOD IV., *Phase VI.*, the lower part of the pumice-bed is again rich only in pieces of old lava, whilst the upper part is crowded with the metamorphic limestones and their derivatives in every stage of metamorphism, and in many localities the upper part of the pumice-bed is almost entirely composed of these rocks, which constitutes, with their rich mineral contents, the great store for collectors of them. This, it will be seen, teaches us that during the first part of the eruption, leucitic rock fragments from the sides and choked bottom of the crater were ejected, and that later the apex of this cavity was carried down into the highly-metamorphosed limestones and possibly (?) subjacent rocks.

On a former occasion I estimated the depth of the apex of the crater of this eruption at about 890 metres below sea-level (*op. cit.* p. 38), so that we may suppose this thickness of rock, aided by the weight of the mountain above, sufficient super-

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incumbent pressure, combined with igneous matter in fusion, to have produced these various metamorphic products.

The Plinian eruption, PERIOD I., *Phase VII.*, tells much the same tale, on a smaller scale, as the last. The deposits of the feeble explosive eruptions that followed it are rich in ejected blocks, but many show signs of being metamorphosed twice over, and many are the calcareo-igneous breccias which it would seem might be due to earlier materials that crumbled into the crater neck and subsequently were re-cooked.

In a considerable number of volcanoes that I have examined, analogous facts were evident; but beyond this the *ejected blocks of a volcano* bear a definite *chemical and mineralogical relationship to its essential ejectamenta and the rocks subjacent to it*, which principle we shall see fully borne out by Monte Somma and Vesuvius.

The stratified limestones have been chosen for the first part of this paper, because their original lithological structure serves as guide and landmark as we proceed from a normal limestone to its extreme modifications. This group exhibits the different changes rather on a miniature scale, but such is of great advantage before proceeding to large rock masses often tons in weight, with in many cases almost a uniform structure. Some chemical investigations have been already undertaken, but it is preferable to consider them more fully when we study the massive limestones and their derivatives.

PART I.

Stratified limestones and their altered and metamorphosed derivatives.—The peninsula of Sorrento, which faces Vesuvius on the south, is composed of a great mass of magnesian limestones at least 4700 feet in thickness. The age of the entire mass is somewhat uncertain, but the upper portion is no doubt of Upper Cretaceous age, which, without any apparent uncomformability, is continuous with the whole of the underlying limestones which are referable to jurassic age.

These limestones are often finely banded, as indicated by differences of colour along the stratification planes. Fossils no doubt abounded, but, by intense mineralisation, are now represented by little else than patches or geodes of white calcite, which stand out rather markedly on the more or less grey, brown, or blackish matrix due to a very general distribution of bituminous matter. Perhaps specimens from hardly any other region of limestone of the same size has been so much analysed. In the following table are included twenty-seven analyses by L. Ricciardi and five by Abich :—

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From "Le Rocce Calcaree della Provincia di Salerno, Gazetta di Chimica Italiana, Vol. XII., 1882, p. 133."

Località and Characters of Specimens.																
Specific gravity	+15C. 2803	*Capo d'Orso.*—Ashy white limestone, compact, crystalline, fracture conchoidal.	+15C. 2481	*Amalfi.*—Dirty white limestone, slightly bituminous, crypto-crystalline, fract. conchoidal, veined in white calcite.	+16C. 2775	*Amalfi-Torre.*—Ashy white, spotted yellow, crypto-crystalline, cont. geodes lined with calcite, splintery fracture.	+16C. 2619	*Amalfi.*—Grey limestone, spotted with yellow, veined white, rich in calcite geodes, crypto-crystalline, fracture conchoidal.	+19C. 2802	*Atrani—Torre Carnao.*—Light grey, shaley, crypto - crystalline, splintery fracture, slightly bituminous.	+18C. 2776	*Atrani—Minori, Piano Moricone.*—Dark grey, compact, fract. conchoidal, bituminous, leaving argillaceous residue.	+16C. 2672	*Ravello—Torre del Carosello.*—Calcareous shale, greyish black, splintery fracture, slightly bituminous.	+17C. 2821	*Majori—Abatia.*—Ashy grey, compact, crypto-crystalline.	+16C. 2828	*Majori—Bellagata.*—Mixture of dark grey limestone and neat crystals of calcite.	+19C. 2838	*Majori—Salicerchia.* — Dark grey, compact, crystalline, fracture conchoidal.	... ...	*Majori—Contrada Nucula.*— Blackish grey, compact, amorphous, fracture conchoidal.	+18C. 2827	*Guardiola—towards Majori—Vena Rossa.*—Light grey veined, compact, rich in rusty calcite geodes, crypto-crystalline,splintery fracture.	+17C. 2815	*Camaverde—towards Majori.*—Dark grey, rich in veins and geodes of calcite,crypto-crystalline, conchoidal fracture, slightly bituminous.	+19C. 2831	*Erchia—Ponte.*—Crypto-crystalline, compact, few calcite geodes, fracture splintery.	+16C. 2836	*Citara.*—Dark grey with yellow spots, crypto-crystalline, veined, rather large calcite geodes.	+16C. 2803	Same as last locality. — White, ashy, and crystalline.
CaO	31·04		53·86		33·03		54·36		34·03		30·82		31·01		31·21		30·02		31·13		55·07		31·16		31·60		30·13		33·04	
MgO	21·28		1·54		19·48		1·64		18·73		17·88		16·83		21·01		22·03		21·56		0·87		21·07		20·78		22·11		18·64	
CO_2	47·29		44·27		47·33		44·02		46·47		43·49		43·23		47·31		48·01		47·61		43·41		47·57		47·78		47·29		46·05	
Al_2O_3	...		...		...		...		...		0·73		1·14		...		...		...		...		...		...		...		...	
Fe_2O_3	trace		trace		trace		trace		trace		trace				trace		trace		trace		trace		0·84		trace		0·12		trace	
Cl.	...		trace		trace		trace		trace		trace		...		trace		trace		trace		...		...		trace		...		...	
SO_3	...		trace		...		trace		trace		trace		trace		...		...		...		...		...		trace		...		...	
Bituminous matter	...		trace		trace		trace		trace		trace		trace		...		...		...		...		...		trace		...		...	
H_2O., at 120° C.	0·19		0·15		0·21		0·12		0·24		0·69		0·35		0·06		0·15		0·07		...		0·14		...		0·21		0·63	
Insoluble residue	...		0·62		...		...		...		6·69		7·95		...		...		...		0·97		...		...		...		1·94	
	99·80		100·44		100·05		100·15		99·47		100·26		100·51		100·11		100·21		100·37		100·82		100·28		100·11		100·28		99·67	

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Abich.	Locality and Characters of Specimens.	Specific gravity	CaO	MgO	CO_2	Al_2O_3	Fe_2O_3	Cl	SO_3	Bituminous matter	H_2O, at 120° C.	Insoluble residue	
	Fiume.—Ashy white, composed of mixture of amorphous and crystallised calcite, compact, rare calcite geodes lined by minute crystals of calcite, fracture conchoidal.	+16C. 2821	30·66	22·04	47·47	...	trace	trace	trace	trace	trace	...	100·17
	Rocca, Vetri—Fontana a Lemie. — Greyish black, amorphous, shaley, bituminous, fracture splintery.	+16C. 2717	34·64	17·47	47·14	...	trace	trace	trace	0·67	0·17	...	100·09
	Same as last locality.—Light grey, crystalline, compact, fracture splintery.	+16C. 2782	30·55	21·98	47·35	...	trace	trace	trace	trace	0·09	...	2·782
	Vetri sul Mare.—Greyish black, shaley, bituminous, fracture splintery.	+16C. 2805	31·37	19·13	46·03	...	trace	trace	trace	8·68	...	...	100·21
	Cava dei Turchi—Monte Pertuso.—Ashy grey, traversed by minute veins of calcite, angular fracture.	+17C. 2801	34·34	19·09	47·15	...	trace	trace	...	...	...	...	100·08
	Same locality.—Banded limestone varying from ash grey to grey, crypto-crystalline, with occasional minute crystals of calcite.	+17C. 2807	32·64	20·38	47·02	...	trace	trace	...	...	...	...	100·04
	Same locality.—Dark limestone, slightly veined, with rare calcite geodes, amorphous, with dispersed crystals of calcite, fracture conchoidal.	+17C. 2804	33·84	18·64	47·16	...	...	...	...	...	...	0·47	100·11
	Monte Sant Angelo.—Dark grey, nearly amorphous, fracture conchoidal.	+16C. 2693	54·13	2·01	44·17	...	...	...	...	...	...	0·58	100·69
	Same locality.—Ashy grey, crypto-crystalline, fracture conchoidal.	+17C. 2792	36·64	16·30	46·63	...	...	...	...	...	...	...	99·57
	Monte Caprile.—Ashy white, crypto-crystalline, fracture conchoidal.	+20C. 2778	32·63	19·82	47·72	...	trace	trace	trace	...	0·24	...	100·41
	Monte Cerreto.—Dark grey, splintery, slightly bituminous.	+16C. 2803	34·24	18·47	46·39	...	...	...	trace	trace	0·18	...	99·28
	Vico.—Hippurite limestone.	...	54·16	0·80	43·45	0·32	...	...	...	1·00	...	...	99·73
	Monte Sant Angelo—Summit.—Brecciated limestone.	...	54·90	0·93	44·17	...	...	...	...	...	...	...	100·00
	Between Minori and Maiori.—Stratified compact limestone, passing into.	...	53·76	1·09	43·44	...	...	...	...	...	...	...	98·30
	Same locality. — Crystalline dolomite in large grains.	...	31·67	20·68	47·65	...	...	...	...	...	...	...	100·00
	Minori.—Black dolomite.	...	30·69	18·57	43·94	0·94	...	...	SiO_2 +	5·25	...	...	99·39

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Generally speaking, the purer limestones are mostly amorphous or crypto-crystalline, whilst the dolomitic ones are distinctly crystallised only in a very few examples, and this is quite a different structure from that which is developed by metamorphic action as exhibited in the ejected blocks.

A large number of specimens show traces of iron, but where estimated even together with alumina it never reaches 1 per cent. Unfortunately, in many of the analyses, the residues insoluble in nitric acid were not estimated, although in two cases they varied from 6 to 8 per cent. This residue, besides the above compounds, no doubt was in part made up of silica. In Abich's analysis, silica and bituminous matter are grouped together, so that it is probable that silica rarely exceeds 2 or 3 per cent., whereas in the greater number of limestones it is absent. The bituminous matter, although having a marked effect in colouring the rocks, yet usually exists only in quantities too small for estimation, except in the greyish black, shaley limestone from Vietri sul Mare, where it exceeds 3½ per cent. The black dolomite from Minori, analysed by Abich, was no doubt as rich in it, but it was not determined separately from the silica. It will be seen also that the greater number of these limestones contain traces of chlorides, and have often sulphates, but in such small quantities that they may be practically disregarded.

The causes of the dolomitisation of these limestones that dip under Vesuvius do not concern our present inquiry, though it may be remarked by the way that the structure coincident with the presence of a large proportion of magnesia in the rock is not such as would indicate any relationship with neighbouring active volcanic agencies. There is, in fact, the clearest evidence that the cretaceous rocks had already taken on nearly their present configuration before the deposition of Eocenes and Pliocenes, which are precedent to the volcanic outburst of the Campania.

These rocks we have been considering are therefore the materials out of which such an extraordinary series of silicate compounds have been developed beneath Vesuvius. That there do not exist the materials in these limestones, out of which peridotes, pyroxenes, micas, and other complex silicates could be elaborated, is self-evident. It is clear that the silica, alumina, iron, fluorine, &c., must have been introduced from without; therefore we have every reason to believe that these substances were derived from the neighbouring igneous magma. By what methods they are introduced is difficult to determine. It could hardly be by osmosis of fluids, because had the limestone been softened sufficiently to allow such to take place, it would not

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have retained all the minute details of its stratification structure. Scacchi has demonstrated that many silicates, such as pyroxene, amphibole, leucite, biotite, nepheline (microsomite), garnet, &c., have been deposited by sublimation. Of course, here is not meant the actual mechanical sublimation of the mineral species, but rather the deposition of a particular species by the reaction of one or more vapours on each other, or on some solid. We find the closed vesicular cavities of old lavas filled by these minerals. It is consequently not difficult to conceive that such vapours as would be required can find their ways between the calcite grains, undergoing decomposition with the formation of the different metamorphic minerals. What these vapours were it is difficult to guess at; but from the great abundance of HCl, SO_3, and HF, it is very probable that these in combination with the required elements did the work, taking an important part, the first and last.

Description of Ejected Blocks.

(205).[1] Coarse granular dark buff limestone, affording a bituminous odour. It is spotted by small geodes of white calcite, and streaked by fissures lined by the same, so that combined with its granular structure the fracture of the rock is very irregular. Faint traces of bedding are present, and an extremely thin light coloured crust exists, which is evidently the effect of weathering by percolating water. Under the microscope (No. 205, Plate XV.) this is a most beautiful rock, being nothing more than one vast aggregate of foramenifera, forming a compact limestone which has been crushed and again re-cemented by infiltration of calcite, forming a micro-breccia. The crystals of the white veins show with the polariscope the beautiful lattice pattern of some calcites. The bitumen is collected in certain cracks and fissures.

(24). This is dark buffish-grey earthy-looking splintery limestone, with a strong bituminous odour when scraped. It is traversed by very fine veins of calcite. Microscopically, it is seen to consist of minute crystalline grains with a very uniform size. The hydrocarbon seems to be scattered between the grains and along the fissures. In the midst of these are many minute oval bodies of clearer calcite that are probably highly mineralised foramenifera. The grains are about one-hundredth of a millimetre in diameter. There is no sign of original crust.

(25). Is a greyish, buff, compact limestone of very fine granular structure very distinctly stratified, the different bedding planes being indicated by variation in colour. Scraped it

[1] These numbers refer to those of the catalogue of my collection, and are employed for convenience in referring to a particular specimen.

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gives out a strong bituminous odour. The darker bands are composed of more minute crystals than the lighter ones, as if the presence of bituminous substance had impeded their growth. There is a layer of from 2 to 6 millimetres of the surface that has been bleached probably by heat during the ejection. Under the microscope the rock is seen to be a fine grained limestone, the average size of the crystals being rarely more than the thirtieth or fortieth of a millimetre. Stratification on a minute scale also exists. The bituminous matter of a very dark brown to black colour is distributed between the grains, but principally in minute druses the size of a few grains, or it forms bands parallel with the stratification. In a few places are minute druses and veins filled by larger and whiter calcite, and in some the centre of the druse contains the hydrocarbon. The white crust differs in no way from the rest, except containing less bitumen, so that it seems that the heat was only just sufficient to volatilise or burn it off without attacking the limestone, unless the attacked part has been lost by solution or abrasion. The grains, both new and old, polarise in brilliant colours, but are very patchy.

(39). Is a markedly stratified limestone, finely crystalline in structure, the grains glistening almost like a saccharoidal marble. It breaks easily across the fine bedding planes, but some more marked bands are sources of splitting. Most of the bandings are indicated by varying shades from light brown to yellow, with a few white and grey, so that the whole seen from a distance appears of a light rusty colour. The crust, half a centimetre, in thickness, differs only that the brown tints change to grey, as if the limestone had been removed or reduced. Under the microscope, the grains are well defined with an average size of from a thirtieth to a tenth of a millimetre, and are somewhat gritty in structure, being choked by fine dark dust and polarise in patchy colours. A very large number of small exceedingly fine grained patches, apparently of calcite, seem to be the remnants of some organisms. Under a high power, no further knowledge can be gained of these bodies. Besides these there are also patches of coarser calcite grains. The colour of the rock is seen to be due to a very large number of decomposing crystals of pyrite surrounded by a cloud of limonite. The crystals vary up to a twentieth of a millimetre in size, and appear to occur as pentagonal dodecahedra. The banding depends on the more or less abundance of these different components. There is no evidence of any bituminous substance.

(52). Very similar to last specimen, composed of white, bluish-grey, and rusty brown groups of strata. The whiter bands are more crystalline at one end of the specimen, and pass into coloured ones at the opposite end. The surface is simply contused.

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(38). Resembles the last to a certain extent. It is a little more crystalline and whiter, with dark rich ferruginous laminæ, so that it splits almost entirely along the bedding planes. It is also slightly faulted.

(48). Much like 52, but colour is a grey, tending towards a greenish tint. The rock is much faulted, traversed by calcite fissures, and contains some small geodes of the same mineral. It seems to have suffered much crushing whilst still plastic, as small faults so die out, and some strata are crushed up or drawn out.

Remarks.—In the first three examples we have as many types of bituminous limestones, such as form a very large part of the Castellamare (cretaceous) rocks, and so unaltered that foraminifera, in one at least, are beautifully preserved, and neither by the naked eye nor by the microscope can any differences be seen, except in 25, in which the hydrocarbonaceous matter seems to be blacker or carbonised, as if a faint baking had taken place. From this group we proceed to a series of graphitic limestones, and their derivatives to be described. The remainder of the specimens seem to consist, for the most part, of ferruginous limestones, with traces of organised structure. They appear to have undergone a very faint alteration, in that they tend to a saccharoidal structure, and some of their calcite grains contain minute impurities, which are probably small peridote and brucite crystals from hydration of original periclase. In one, at least, we have pyrites which might have been introduced by the percolation of water containing sulphuretted hydrogen. This second group, therefore, seem to show a very faint change tending towards metamorphism, which we shall see increases, so that these latter slightly ferruginous rocks, which were probably never bituminous, give rise to derivatives quite different from the last.

(202). Carbonaceous limestone, with very strongly marked bedding, which beds vary in colour from almost black to light grey. The more carbonaceous bands are much finer grained, whilst the lighter ones are almost saccharoidal in structure. When scratched no bituminous odour is emitted. No crust apparent. As the specimen is one of the darkest in colour amongst this type of limestone, I estimated the amount of carbon contained in it. It afforded 0·608 per cent., or a little more than a half per cent. This carbonaceous matter is structureless, and exhibits all the characters of graphite. (27·7150 grams of limestone were dissolved in dilute hydrochloric acid, evaporated to dryness, re-treated with dilute HCl, and filtered. The black residue, after prolonged drying at 200° C., weighed 0·7500 grams, which on being calcined at a white heat lost

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0·1685, which was counted as carbon. The siliceous residue, which was therefore considerable, being equal to more than 2 per cent., gave a strong reaction of iron with borax bead, and was therefore probably some silicate of that base.) The specimen chosen for analysis was an average of all the bands, of which the dark ones predominate, and which, if polished, would be of a good black colour. It is remarkable how far less than 1 per cent. of graphite is capable of changing the colour of limestone. The calcite grains are very small when the carbon is most abundant, but in the lighter parts they range up to half a millimetre in diameter.

(31). Banded limestone much the same as last, but little coarser and of general lighter tint. Exhibits three beautiful little faults in one hand specimen 12 centimetres long, each one being filled by white calcite. Calcite grains reach half a millimetre in diameter.

(215). Same as last, but very finely stratified, and most beautifully exhibiting contortion equal if not superior to any piece of paleozoic or archean mica schist. Calcite grains measure half a millimetre or more.

(32). Very finely banded carbonaceous limestone, differing from the last three only in the lighter part, being much more coarsely crystalline. Two sections were made of this rock. (Fig. 32, Plate XIII.), which shows the junction of fine and dark bands, with coarser and lighter bands. In the former the graphitic matter forms a trabecular network surrounding each grain; but in the latter, one or two rows of calcite grains are separated from their neighbours above and below by a band of graphite, which, in some cases, sends a branch in between the individuals constituting the particular band. The calcite crystals are very pure, only containing a few scattered, very small undeterminable microliths. They offer most beautiful examples of twining, banding, and the lines of cleavage are very marked, whilst a faint granular structure sometimes is evidently carefully manœuvring between crossed nicols and using the quartz plate. The crystals forming the coarser bands average two-thirds of a millimetre, whilst those of the finest have a diameter of about half of a millimetre.

(33). This specimen consists of a coarse-grained banded carbonaceous rock of lighter colour than those above described, whilst the other half is a beautiful snow-white, saccharoidal, compact, marble. It shows evidence of a more advanced metamorphism, and the white part is no doubt due to the removal of the carbonaceous matter. In the midst of the banded part a small druse may be seen, containing fused beads

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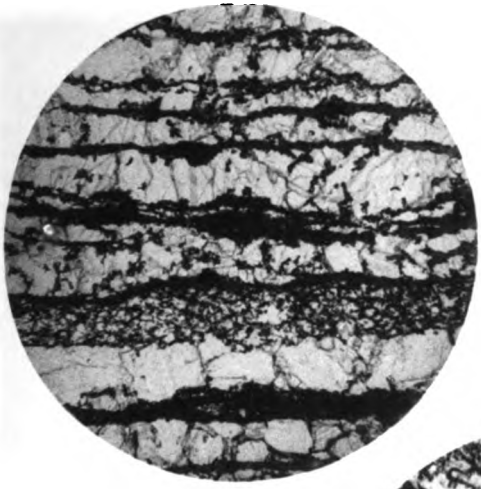
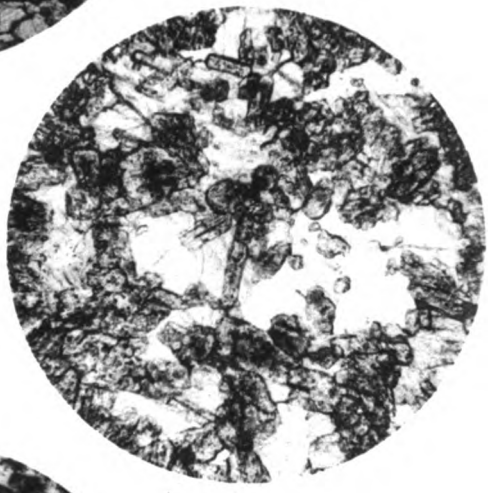


N.° 32.

x 24 diam.



N.° 40.

x 24 diam.

N.° 41.

x 24 diam.

EJECTED BLOCKS OF MONTE SOMMA

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or tears of calcite crystals,[1] with a few milk-white ones of some other mineral. Attention is drawn to this specimen in relation with a group of geodic limestones to be described. The geode cuts through the stratification banding, and its walls consist of different layers of variously tinted limestone. The grains of the white marble attain as much as 1 millimetre or more in diameter, whilst those of the black part rarely exceed a half of that.

(35). Consists of a banded carbonaceous limestone, showing faulting, and forming about one-third of the specimen, whilst the remaining part is a white saccharoidal marble. This latter consists in part of very fine-grained rock, and another portion rather coarse. Separating these two portions is a thin band of a pink fibrous mineral. In this specimen its fibrous structure is not very evident, but in others it is more marked, and as it is of very common occurrence a graduated series of specimens can be obtained from this through beautiful silky to coarse fibrous varieties, and finally to a net-work of distinct wollastonite crystals. I have prepared microscopic sections of the more evidently fibrous varieties, and so far as they can, they exhibit the optical properties of wollastonite. The extinction in these varieties is always parallel with the axis of the bunch of fibres, but deeply embedded in these are numerous grains and crystals of white peridote, so that any attempt at a separation by heavy solutions would be quite unavailable. Amongst the eighty specimens of ejected blocks examined by Mierisch, this variety probably was not represented, as he makes no mention of it. Vom Rath had, however, a specimen upon which he expresses his opinion that the wollastonite was directly derived from the limestone. This band is separated from the carbonaceous portion by 3 to 4 centimetres of the white marble. At the junction of this latter with the former is a thin zone of dark granules, which appear to consist of periclase.

(42). This is a remarkable specimen—nearly a half is a coarse and fine grained stratified carbonaceous limestone, which passes into a very white saccharoidal marble, and this again into a banded mass of pink wollastonite and a green mineral, which in its turn is followed by more white marble. Microscopical preparations were made of this specimen. The banded limestone is very similar to 32, but one broad black band farthest away from the metamorphosed part is very fine grained, whilst the rest is very coarse, the grains being in some cases double the size of those in 32.

[1] Mierisch discusses these solidified drops of calcite, but I had already, some years before, explained their origin.—Q.J.G.S., 1884, p. 82.

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Exceptions to this occurs in the dark band, where the presence of much carbon seems to have impeded the formation of large crystals. As the white saccharoidal part is approached, the calcite crystals become larger, and the carbon grains appear to be often enclosed within them. The saccharoidal part shows an aggregate of calcite crystals free from carbon and comparatively pure, only showing what appear to be streams of extremely minute gas pores, with a few scattered grains of peridote. The number of these latter appear less than is really the case, which is probably explicable by their being in part lost amongst the grains of calcite, where from their small size they are not very visible in polarised light. The matrix when dissolved in a dilute acid leaves a considerable deposit composed of these crystals, which contain numerous minute grains of a greenish-brown colour. Many of these are octohedrous. In the residue are unenclosed crystals of the same characters, with hollow faces. All are very minute, and only visible under $\frac{1}{8}$ objective. They are probably fluorite.

The silicate part consists of two bands, about half a centimetre wide, of pink, fibrous wollastonite, which include between them about 2 centimetres of fine, light green, banded rock, which, were it not for the colour, might be taken for the carbonaceous limestone. Microscopically, it consists of an agglomerate of light greenish peridote with a little calcite, whilst the banding consists of a mass of small grains, which seem to be a mica. Scattered here and there, and sparingly, are some structureless, colourless, irregular patches of a mineral which polarises in the first order of colours. It looks much like a monoclinic felspar, but if it is so, its associations are curious. There are also banded patches of a single refracting transparent crystalline substance, which I suspect to be fluorite. Lastly are a few stellate groups of galena. The before-mentioned pink bands are composed of a fibrous mineral, arranged in tufts at right angles to the bedding plane.

Where these wollastonite fibres project into the white crystalline limestone, they are mixed up with numerous peridote crystals. They afford an excessively opaque preparation, and it seems impossible to determine the angle of extinction of the fibres, so that I refer it to wollastonite, which it much resembles in its reactions, and in that it can be traced through intermediate specimens to undoubted examples of that mineral as already mentioned. No doubt this opacity is due to that stage of decomposition described by Mierisch (*op. cit.* p. 173), which results in the peg structure in the better defined crystals of this mineral.

It will be seen that in this specimen we have three degrees

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of metamorphism in a certain order, *i.e.*—1, Carbonised limestone; 2, saccharoidal limestone, with peridote and fluorite (?); 3, limestone, nearly replaced by different silicates, sulphides, and fluorides. But another point of equal interest is that at one end of the specimen the saccharoidal encroaches on the carbonaceous limestone, and the former is in its turn invaded by the pink fibrous bands, and at the same time the banding of the silicate part is, to a considerable extent, obliterated.

(40). Is an extremely strongly marked stratified rock. First, we have about four centimetres of a dirty-white crystalline limestone, the outer third showing by varying tint and coarseness extremely fine banding. This limestone is in some parts marked by small brown radiating dendritic spots. It is very uniform in texture under the microscope, and exhibits a few scattered grains of white peridote. Abruptly in contact with it, we have about three centimetres of a dirty green rock showing by its varying tints much stratification, banding, and in some parts coarsely crystalline. At this point, long irregular spaces exist, into which project the crystals, which may be distinguished by the naked eyes as green biotite, with (what can be proved chemically to be) calcite. This green banding is seen under the microscope to be composed of a network of large crystals of nearly colourless pyroxene in a matrix of calcite (Fig. 40, Plate XIII.). Clear light yellowish-green biotite crystals are also abundantly intermixed. Near the open spaces, however, most beautiful long hexagonal prisms of the latter mineral project, so that often their length may be ten times their diameter. They are generally imbedded in some mineral apparently structureless, but polarising in the most brilliant colours. It was impossible to isolate this mineral, and, as it fills up irregular cavities, it could not be determined. Were it not for its associations, it might have passed for quartz, but which would lead one to refer it to peridote.

The pyroxene crystals polarise in unusually brilliant colours, but are remarkably irregular in structure, each individual appearing between crossed nicols as a beautiful variegated mosaic. It is the diversity of size of these, and the greater or less proportion of calcite and mica crystals, that determine the difference of tint and coarseness of structure of the different component bands of this silicate stratum. The largest crystals of pyroxene reach a millimetre in length, they are rather rounded at their extremities, and very irregular in structure. This irregularity, when examined under a high power, is constituted by a number of granules, but principally by a viriditic matter that permeates the crystals, apparently along fissures in it somewhat like moss-agate, but less regularly. There is also

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a faint cleavage, parallel to one or more of the prismatic faces. In the calcite, a few most beautifully perfect cubic crystals occur, which, in all probability, are fluorite.

Separating this band from a similar one of about two centimetres in breadth, is one of limestone of about one-and-a-half centimetres, with the characters as the former one of this specimen. The silicate bands, however, in some places encroach on the limestone bands, and *vice versa*, and in the small silicate bands streaks of limestone are left.

(41). This is a small, but very remarkable specimen. It exhibits a most evident stratification, due to the great contrast in colour and structure of the different bands composing it. The most marked band of over two centimetres in thickness forms about half of the specimen. It is of dirty green grey colour, looking like a compact marly limestone, with minute dedrites along its fracture planes, though between these it breaks with a feebly conchoidal fracture. It is much darker in colour in contact with a little syenitic (?) rock attached to it on its outer surface, but much more marked where it is joined to the next band. The principal constituent seems to be grains of calcite below $\frac{1}{250}$ of a millimetre in diameter. The mass is also traversed by a few minute viens of calcite. This rock dissolved in dilute acid leaves a fine grey powder, or skeleton, which is composed of microliths about $\frac{1}{400}$ of a millimetre in length, and a fourth or fifth of that broad. Although so small, these crystals polarise up to brown yellow in the first order of colours. There is little doubt that they are peridote. This is the micro-felted structure observed by Mierisch (*op. cit.* p. 132) in drusy limestones, a hydrous silicate analogous to serpentine, but poor in iron.

The dark bands are much more marked microscopically, and are so insoluble in dilute acid as to retain their form after treatment with such. Judging from analogy rather than by certain facts, it would seem that these bands consist of a few minute grains of peridote intermixed with greenish biotite microliths, that do not attain the $\frac{1}{100}$ of a millimetre in diameter. In striking contrast with the last described band is its immediate neighbour, separated abruptly from it, and consisting of more than a centimetre of coarse white saccharoidal limestone, with various colourless inclusions, besides grains of more or less dark colour. Some of these are rusty-looking, others metallic, consisting of decomposed pyrite and galena. Microscopically, the mass is composed of grains of calcite averaging from a-half to one-and-a-half millimetres in diameter, which show the most beautiful lattice polarisation. Mixed with these are the galena and decomposed pyrite crystals already

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mentioned. There are a few scattered groups of peridote very much fractured, and the fissures threaded through and choked by what appears a dirty amorphous (?) matter, probably pilite or some other hydrous silicate nearly allied to serpentine (Fig. 41, Plate XIII.). Mierisch (*loc. cit.* p. 139) observed no inclusions in the forsterite, which is quite contrary to my experience, especially in large crystals such as those just mentioned, in which case there is little doubt that the substance is a decomposition product. In some points occurs a colourless mineral of irregular outline, but somewhat streaky on account of many enclosed gas and liquid cavities; it also shows faint banding like the teeth of a comb, also stallate acicular inclusions. One crystal showed a clean rectangular outline at one corner, with this banding parallel at its edges it afforded parallel extinction. Some of these crystal grains were isolated, when they are then indistinguishable from those of peridote.

There are a certain number of crystals of a bright green colour (seen best by dissolving the rock in weak acid), a few of which are well-formed. They show no pleochroism, and give extinctions such as to indicate pyroxene. Some enclose a brownish nucleus which gives no characters sufficient to distinguish what it is. One might at first suspect amphibole, but it may probably be referred to a different coloured pyroxene from its host.

Scattered about are also a number of fine prisms and plates of a light brown biotite which are quite transparent and free from enclosure. There are also certain spots where an aggregate of clear grains always remain black, whilst rotated between crossed nicols. There are also a few very minute octahedra enclosed in the crystals of calcite. Probably both of these are nothing more than fluorite. Both the pyroxenes and the micas are more abundant along the limits of their containing band. A few crystals may also consist of idocrase.

Next comes a thin stratum less than a millimetre in thickness, identical in structure with the dark band of microlitic biotite already described as limiting the crystalline band on the opposite side. This thin stratum contains some very minute black opaque stellate crystals of unknown composition.

Following the mica band, we have a stratum of about half a centimetre of fine granular calcite differing from its neighbour already described in many points. In the first place, the grains do not exceed the $\frac{1}{25}$ of a millimetre in diameter, or about thirty times smaller than the others: next, there are very few, if any, admixtures of other minerals, except one very narrow band of dark red colour, which microscopically seems to have consisted of pyrite grains which have undergone decomposition. The

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calcite crystals contain a few impurities in the way of undeterminable grains and mocroliths.

Again comes another very thin though double microlitic mica band, followed by a stratum from two to three millimetres thick, resembling in general appearance and coarseness the thick coarse crystalline band already described. There are the same sulphides, pyroxenes, mica, and a few large calcite grains, but most of these are replaced by a clear colourless mineral, except for many inclusions, in equally large grains, but *all sections* remain dark between crossed nicols. The grains have no definite outlines. Some others identical in appearance and inclusions do polarise; there is therefore some doubt whether this mineral may not be tetragonal or hexagonal, rather than isometric, for in two cases it was possible to obtain a faint axial figure though very feeble and imperfect. So far as meionite goes, Mierisch (*op. cit.* p. 49) says it is most difficult to prove that mineral in sections. Grains were isolated and tested, but gave no fluorine reaction. It is not improbable then that the mineral is either nepheline or meionite. This stratum is separated by a thin imperfect band of microlitic mica from another layer of rather fine grained saccharoidal calcite.

(36). Presents the same order of carbonaceous saccharoidal, white saccharoidal, and stratified silicate rocks. The carbonaceous limestone part is very incoherent, crumbling down in the fingers to a fine sand. Otherwise the characters are the same as in other specimens already described, though the carbon is not distributed in bands. The white saccharoidal portion into which the last graduates exhibits the usual characteristics. This white marble terminates abruptly in the silicated part.

The silicated rock is of pale, dirty green colour, and at the distance 4 or 5 centimetres from the limestone becomes of a very coarse grained granitic structure, and somewhat cavernous. It is divided by a band of limestone, which in one half of the specimen has undergone very considerable conversion into silicates. The constituents of the mass show in grain and composition a very evident stratified arrangement, which, however, is much less distinct on the side where the limestone band is enclosed, thus indicating the direction from whence came the metamorphic action, and that the chemical change was only in part guided by the varying composition of different bands.

Microscopically and also macroscopically, this is a very complex rock. It is composed of irregularly shaped grains of various minerals, none of which show any approach to definite outlines. Beginning with the most recognisable, we have large prisms (these are the best formed crystals) of dirty green to brown biotite, which are most abundant near the limestone

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bands; they are apparently of late formation, as they occupy in part or wholly cavities amidst the other ingredients. Next, we have an agglomerate of crystals of white peridote of the usual type, and also crystals of calcite. These are variously mixed in the two bands with moderate to very large grains of a nearly structureless mineral, polarising in greys or brown yellows; some sections of the mineral remain dark; in all positions between crossed nicols there is no twining visible, so that the mineral is probably nepheline, which is further indicated by its solubility in dilute acids. Between crossed nicols much of the field becomes and remains obscured also by structureless and irregular crystalline grains, which are probably referable to some mineral with the similar characters as that contained in specimen 41. Lastly, there are a number of large white pyroxenes (?) some mottled with clear light green patches. Besides these are vast crowds of smaller somewhat greener crystals of the same, which range down to microliths and form numerous enclosures in the different other minerals already described, so that any attempt at separating the different elements according to their specific gravity, or an endeavour to employ micro-chemical methods, is rendered impossible. In addition to the above main constituents of the rock are a number of ochre patches, probably derived from decomposed pyrites, besides traces of galena. The minute fissures, some cavities, the interspaces between the crystals, and even within some crystals in special planes, occurs a brown or more properly buff granular matter insoluble (?) in dilute acid, which seems to bear some relation to the pink wollastonitic matter in some of the other specimens.

(37). Presents the usual order of alteration. The carbonaceous limestone part is more compact than in the last specimen, and possesses minute drusy cavities lined by carbon, which in the rest of the rock fills in a few interspaces between the grains. The white band resembles much the last in structure, except for the absence of the carbon. There are a number of minute black spots to be seen both in the white and grey limestone, which appear to consist of galena. Macroscopically, the silicate portion of the specimen is of a dirty greyish-green colour, compact in structure, breaking with an irregular crystalline and sheeny surfaced fracture. Large grains of galena and ochre patches from decomposed pyrites are scattered through the mass. The components of this rock are much the same as No. 36, except that the intermingling of the different mineral species with each other is still more intricate, whilst the nepheline which constitutes so much of the mass is not only crowded by the green augite microliths, but is in some cases traversed by large fan-like bunches of very minute curved

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acicular crystals, whilst the calcites show very much of this fibrous inclusion, but exhibit hardly any characteristic twining, so as to render their determination rather difficult. The latter mineral seems to have separated out the last, and may in part be derived from the alteration of the fibrous wollastonite, as indicated by Mierisch (*op. cit.* p. 173).

(54). Here we have an exceedingly hard fine grained limestone, and where not influenced by fissures, it breaks with a porcelain-like fracture, which material it much resembles in appearance. No very evident signs of original stratification are distinguishable. Adjoining the limestone is an irregular band of dark green colour from a half to two centimetres thick, this latter thickness being due to tongues or spurs of the material projecting into the limestone. This band is composed of an intricate blending of minute biotite crystals of not more than a quarter of a millimetre across. The rest of the specimen is of a coarse granitic structured cavernous mass composed principally of biotite, calcite, and a greenish-white mineral mostly in irregular masses, some of which are a centimetre or more long; a few, however, remind one of sanidine crystals in outline (Fig. 54, Plate XIV.). The fracture of this mineral seems to be very irregular somewhat granular, but in one or two places there is a faint appearance of cleavage. The hardness is about that of oligoclase. This mineral occurs in patches, and in that situation envelopes the crystals of biotite. The mica is of dirty green colour, with a greyish tinge towards the centre of the crystals, which range up to three millimetres in diameter. In the majority of cases the crystals may be broken indifferently in any direction, basal cleavage, except at the surface, being almost abolished. Lastly, we have a number of white crystals of calcite, which partly or entirely fill up the interspaces between the biotite, and are scattered over the interior of the minute caverns.

Microscopical examination explains all these uncommon characters in the different compound minerals.

The biotites are crowded by minute prismatic microliths, polarising in strong colours, which rarely exceed the fortieth of a millimetre in length. Strangely enough, although forming the bulk of the crystal of biotite, so as to constitute a large nucleus, yet surrounding this nucleus is a thin zone of very pure mica substance, absolutely free from the enclosures. It is impossible to determine the nature of these microliths, since they are imbedded minerals. Not as in many other inclusions in mica do they follow the planes of cleavage, but are oriented in all direction and so act like pegs in the building up a shoe-heel, holding together the different layers of leather in one, or crystalline laminæ in the other, in consequence of which, the beauti-

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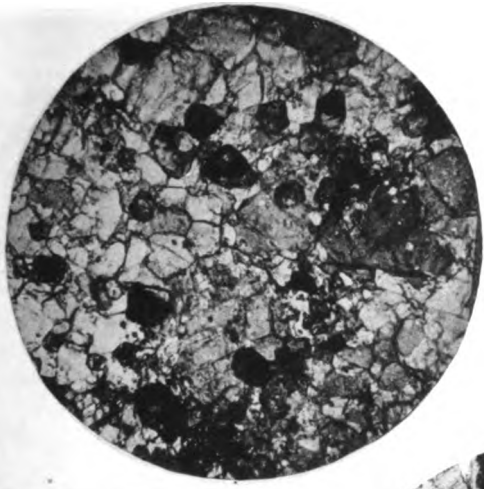
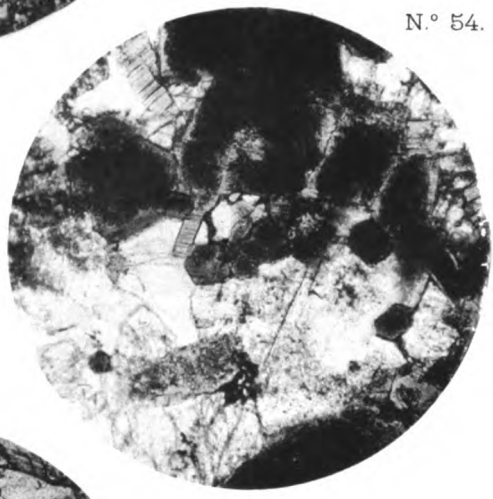


N.° 47. PL

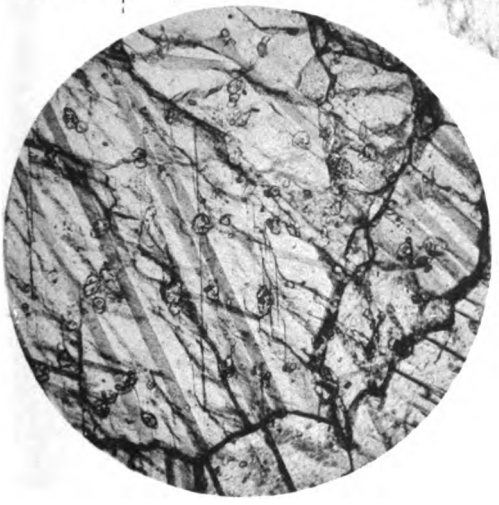
x 24 diam.

N.° 54.



N.° 161. PL

x 24 diam.



N.° 200,a.

x 24 diam.

EJECTED BLOCKS OF MONTE SOMMA

JOHNSTON - LAVIS, PREP. et PHOT.

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Roma Fototipia

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ful basal cleavage is almost totally destroyed in the crystals of biotite under consideration.[1]

The greenish white mineral is in most cases so crowded with the microliths, that it becomes an almost opaque granular mass. In the clearest examples, it seems to polarise in brilliant colours.

The calcite occurs in large grains rarely showing any lattice structure, and although often very dirty, it is generally free from the microliths contained in its neighbours. There are a few other crystals, some of which resemble sanidine, and others that may be nepheline, which are also in great part filled by the small microliths.

As to the nature of these microliths, as already mentioned, little can be said. If examined with a high power, they are seen to be well formed, generally with an oblique termination, and I am inclined to think that they are minute pyroxenes.

The lower part of the specimen is composed of a pulverulent light green granular rock, which is arranged in a somewhat patchy manner in its relation to the already described granitic structured portion. It gives no effervescence with acid, and when sectionised, is seen to be an agglomerate of minute grains having the character of white peridote associated with very little amorphous binding (?) material.

The whole specimen shows somewhat indistinct stratification, and as already stated, contains many irregular cavities lined by somewhat green prisms of biotite, on which in some places are very minute rosettes of a light greenish-white opaque mineral, too small to be determined.

(161). Resembles much in structure and appearance the granitoid part of the last specimen (54). In this case, stratification is indicated by numerous bands of finer grained material. The component minerals are the same as in 54 with their same enclosures of microliths, except that the latter are much smaller and more ill defined. In the cavities are to be seen a clear structureless mineral, with often a nucleus of microliths; it polarises in grey and brownish yellow, with crystalline boundaries, which in one case in the section seemed to be hexagonal and dark between crossed nicols; this mineral I take to be nepheline.[2] Another mineral occurs polarising in dull grey, with many sections showing rectangular outlines, and also with a nucleus of microliths. From the small quantity of material at my disposal for examination, much doubt exists about this

[1] Mierisch (*op. cit.* p. 134) says that in the specimens he examined, which were chiefly drusy limestones, the micas very rarely exhibited inclusions. This is quite contrary to my experience in these altered stratified limestones, for here the mica is very rarely pure, and, in the specimen under discussion, probably more than half of the mass of the crystal is made up of a foreign mineral.

[2] Mons. Renard, to whom I showed the slide, was also of that opinion, and considered the following referable to the same species.

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species, although it is certain that it extinguishes lengthwise parallel to one of the nicols. In (Fig. 161, Plate XIV.) one of these crystals projecting into a cavity is shown with a depressed centre and bounded by apparently numerous zones of very narrow facets, whether these are facets or accretion zones, it is difficult to say. They, and even the mineral, are almost invisible in ordinary light, owing to the index of refraction being very near that of Canada balsam.

There are also patches of the same fine granular peridotic material, as in No. 54. Besides the above-mentioned minerals, some minute crystals of whitish pyroxene are rarely to be seen projecting into the rock cavities.

(200). This specimen consists of the three usual portions. The carbonaceous part is a compact crystalline dark grey limestone, composed of grains, which attain as much as two millimetres in diameter. Microscopically the carbon grains reach as much as a $\frac{1}{40}$ millimetre in diameter, and are chiefly enclosed within the crystals of calcite, which possess marked lattice structure, and also contain a few grains of white peridote. These latter inclusion increase in number and size, whilst the carbon grains proportionately diminish, as the second division or white limestone is approached. Near the junction of the grey and white portions of the limestone, many of the peridotes are attached to or enclose the carbon (Fig. 200*a*, Plate XIV.) This was made evident in a striking manner by dissolving the limestone in very dilute HCl., and washing the insoluble part immediately all the calcite was dissolved. Part of the residue was mounted in balsam, another portion was calcined in a stream of oxygen and mounted, and the third portion attacked by HF and H_2SO_4, washed and mounted. The first preparation shows, in a remarkably interesting manner, the peridote and its carbon enclosures, besides a few beautifully formed hexagonal plates of white mica; the second, the same minerals totally free from graphitic contents; and the third, the carbon residue which, examined by reflected light, displays the metallic lustre of plumbago, as it does likewise when rubbed between the fingers or on paper.

The silicate portion of the specimen is of dirty white colour, with large patches of pyrites, surrounded by a limonitic coat. The fracture is tough, and the surface very hard, with a considerable number of cleavage planes of silvery white mica. At many points stellate or radiate structure is discernible, much like what we see in certain quartz-bearing rocks.

Microscopically, nearly the whole mass consists of an intimate mixture of grains and deformed crystals of white peridote and white pyroxene, the crystals of the pyroxene becoming larger the farther we recede from the limestone portion. The order

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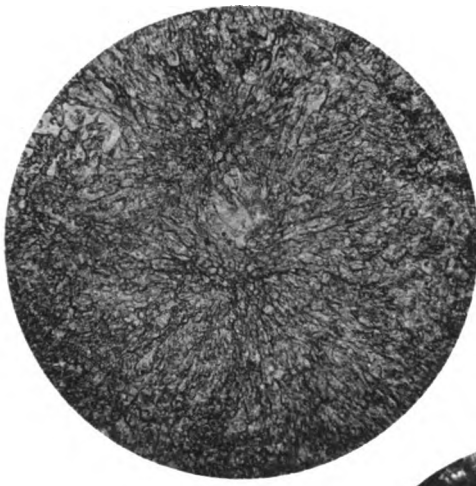
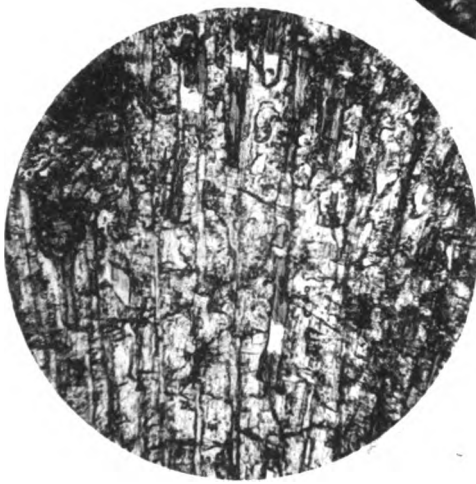


N.° 200,b.
x 24 diam.

N.° 205.
x 24 diam.



N.° 336.
x 24 diam.

EJECTED BLOCKS OF MONTE SOMMA

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of crystallisation seems to have been first olivine, then pyroxene and mica, and, lastly, the few interspaces are filled by calcite. The peridote, mostly in small rounded grains, assumes a rather marked radial form, and when viewed between crossed nicols, forms one of the most gorgeous rock sections one can see (Figure 200*b*, Plate XV.). The pyroxenes are mostly in moderately large grains, rarely showing any crystalline outlines, and hardly any cleavage planes, which, when present, are most irregular. In fact, it is an extremely difficult matter to distinguish the peridotes from the pyroxenes, the only way being by the angle of extinction, which, in very few cases, can be carried into practice, on account of the absence of crystalline borders. Much of the pyroxene contains more or less of the peridote grains. The same enclosures are met with in the white mica, which rarely shows definite outline. There are a few irregular black patches which may be magnetite, carbon or spinel, though there is little doubt that they should be referred to the spinel. The calcites in the silicate part are finer and polarise in feebler colours, and the lattice structure is less than in the marble part. Here it contains a few scattered colourless grains, with a double refracting crust and anisotropic nucleus, being crystals periclase altered on the surface to brucite.

(336). (Plate XV.) In this specimen, the limestone is white, somewhat chalky, but otherwise resembles that of 54. Between this portion and the silicate part, is a minute greyish finely crystalline band, about one millimetre thick. Adjoining occurs from five to seven centimetres of silicate rock, forming the bulk of the specimen, and consisting of fan-shaped radiating rods of a very light green mineral, interspersed with crystals of grey biotite. A distinct cleavage is discernible parallel to the long axes of the rods. These fans of crystals have their bases *away* from the limestone part, and their lines of growth always towards it with but at a slightly varying angle. That is, they indicate the direction metamorphic action extended. Lastly, we have an agglomeration of minerals almost identical with that of specimen 54, even to the pulverulent light green granular rock and the minute light green rosettes of an indeterminable mineral.

The thin band next the limestone consists of an agglomeration of minute grains of white peridote, the part away from the limestone being of a greenish hue, probably due to an admixture of biotitic material between the grains. In the limestone near this band are a number of outlying grains of peridote, as it were so many outposts, which diminish in number as the distance increases from the silicate portion. At the junction also are brown spots of limonite, probably from decomposed pyrites. The fibrous portion is a peculiar rock, and is not rare amongst

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the ejected blocks of Monte Somma (Figure 336, Plate XV.). One specimen in my mineral cabinet is traversed by thick veins of galena and traces of garnet, and at certain points small cavities occur into which the terminal rods project as minute crystals less than a millimetre broad. On detaching some of these, and measuring the angles of the prism, the determination of the species as being pyroxene was made certain. Sections of this rock form very beautiful preparations. The large radiating fibres polarise in most brilliant variegated colours, and when rotated between crossed nicols, the extinction sweeps across the field, showing aggregate polarisation. Many crystalline rods give an extinction near pyroxene.

To have an independent judgment I put the minute crystals in the hands of my friend Prof. E. Scacchi, who has taken much trouble to carefully measure them with the following results:—"The crystals examined are very small, their form is indicated in the adjoining figures, of which the upper represents a vertical projection of one of the crystals, and the lower the corresponding horizontal one. Their length is usually about a millimetre, and the greater thickness about $\frac{1}{4}$ of a millimetre. The crystals, according to their symmetry, are monoclinic and the faces met with are as follows:—*A* (100), *B* (010), *C* (001), *m* (110), *n* (101), *o* (111): Of them the most developed are *A*, *m*, *o*, *C*, *e*; whilst the other two, *i.e.* *B* and *n* are very minute and often wanting. The faces *o*, *A*, *m* give with the goniometer a good image for measuring the angles, the others give images that are not very clear.

"From the inclinations found one concludes that the crystals are those of pyroxene. In the following table opposite the angles given in the first column, in the second column are the mean value obtained for them from the number of observations in the third column. In the fourth column are the respective values for the angles of pyroxene given by Des Cloiseaux (Manuel de Minéralogie, 1862, pages 52-54). The latter, for convenience, have been reduced to their supplements.

Angles.	Value.	Numbers.	(Des Cloiseaux).
$C : A = 001 : 100$	74° 9′	4	$ph^1 = 73° 59′$
$C : O = 001 : 111$	33° 59′	2	$pd^1 = 33° 50′$
$C : m = 001 : 101$	79° 41′	2	$pm = 79° 23′$
$C : n = 001 : 110$	31° 27′	1	$pa^1 = 31° 23′$
$A : o = 100 : 111$	53° 51′	2	$h^1d^1 = 53° 50′$
$A : m = 100 : 110$	46° 25′	2	$h^1m = 46° 27\frac{1}{2}′$
$A : B = 100 : 010$	89° 57′	1	$h^1g^1 = 90° 0′$
$o : o' = 111 : 111$	48° 37′	2	$d^1d^1 = 48° 33′$

"EUGENIO SCACCHI."

"*April 28th*, 1888."

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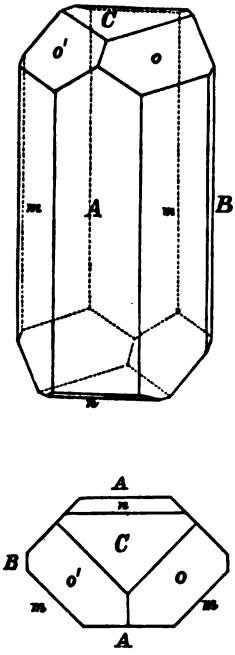

In fact this specimen combines the character of 54 and 200. The rods have very irregular surfaces, and all parts of the same rods do not extinguish at the same angle. The interspaces between the rods and bunches are filled by biotite, and in the latter case this mineral occurs in comparatively large clear crystals of a beautiful well-marked bottle-green colour. Also in a few spaces, small portions of calcite and nepheline (?) occur.

For the remaining part of the specimen, nothing need be said except that the mica prisms show a somewhat radial arrangement, and exhibits, though to a less degree, the same microlithic inclusions as this mineral does in 54.

(49). Is a small specimen consisting of a fine grained grey carbonaceous limestone, a white marble band which contains much white peridote, and while this is most abundant, a band about $\frac{1}{2}$ to 1 centimetre thick of finely crystallised pyroxene. It is only this pyroxene band that gives any particular interest to the specimen, and that is due to the bright pistachio verging on emerald green colour. In two specimens in my mineral cabinet a white limestone contains this variety of pyroxene beautifully crystallised. In this specimen, on account of the

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absence of crystalline boundaries to the mineral, the defective cleavage and much internal tension of the crystalline fragments, it might be easily mistaken for peridote.

(337). This specimen consists of the following portions:—About 1 centimetre of white crystalline marble; one and a-half centimetres of a compact, coarse crystalline green band; two to three centimetres of very coarse crystalline rock, consisting of large grains of calcite, three or four millimetres in diameter, with a buffish white granular mineral. Besides these is a small crystal of idocrase and a patch of garnet. Then comes a centimetre of the same rock, with much green mineral and bits of garnet and idocrase. Lastly, we have again the same rock, though much coarser, with less of the green mineral, but with many large crystals, a centimetre or more in diameter of garnet.

Microscopically, the marble portion shows nothing new, but the remainder is very interesting, and may be described in general, as the banding is simply due to the prevalence of the green mineral.

One of the first species that seems to have crystallised has been the white peridote, which has separated out in bunches of flattened prisms, so as to be quite pointed in section, and project into the calcite. This mineral is split up by numerous fissures, filled by a fibrous substance or pilite. On one half of the section that has been etched by weak acid, the surface of the mineral is exposed, and is covered by markings both in colour and lustre, like a layer of dried and cracked gum. Some crystals, however, are very slightly altered or fissured, and they then polarise most brilliantly.

Especially in the green parts are large numbers of crystals and microliths of dark grass-green pyroxene, many of which are perfectly formed, and possess fairly well-marked cleavage. They exhibit a slight amount of pleochroism and polarise—in very strong colours. Their extinction angles are high. They form chains, patches, and form inclusions in all the other minerals, and seem to be the further development of the analogous microliths in specimen 54, &c.

There are a few crystals in the green bands of greenish brown biotite. Very considerable also are the nephelines, which are moderately clear, and in many cases have fairly distinct outlines. The garnets are of light straw colour in section, and are much inter-crystallised with sodalite and peridote, though this last seems to have been the earlier to separate. Neither of these species are mentioned by Mierisch (*loc. cit.* p. 145) as inclusions in garnet. Besides this, the garnets are much zoned, and some of these layers are separated by a stratum

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of pyroxene crystals. The garnets show weak double refractions, and have no definite boundaries, so that to the naked eye they seem to graduate into the surrounding rock.

Where the garnets are most abundant, that is, farthest from the limestone, are large grains of sodalite with irregular contours. This mineral is very rich in minute enclosures, which seem to be of the nature of crystalline grains when examined under a high power, though they appear to be isotropic. The calcite grains fill up the interspaces; they show good ribbon and lattice structure.

This rock still shows with sufficient distinctness indications of its original stratification structure. It may be regarded as a more advanced stage of metamorphism of the type of specimen 41, and is one of the most remarkable examples of the passage from a sedimentary limestone to the characteristic mineral aggregates constituting the rich mineral-bearing ejected blocks of Monte Somma, and yet at the same time retains those indications of stratification which is an index guiding our investigations through the obscure and intricate processes of mineral replacement. Another important point about this specimen is that a number of its mineral components have been elaborated from limestone by the introduction of the necessary materials without any local disturbance, and not from detached fragments of lava constituting the druse materials upon which so much stress is laid by Mierisch. In fact, a number of these species were considered by that author to occur only in the druse filling materials. I propose to discuss this question in another paper.

(46). This is a unique specimen of metamorphism with which I have met with at Monte Somma, but it is necessary to describe it, as it may bear some relation to a somewhat similar change in some massive limestones from the same locality. It consists of a series of fine and coarse strata, some consisting of a dirty white, chalky-looking, compact limestone interlaminated with a white translucent material. In this specimen one side has been exposed to percolating waters, which seems to have dissolved away to a less extent, the chalky-looking part, which stands out, and is traversed by numerous open fractures, so as to look quite brecciated. These fractures, however, do not extend into the interior of the mass, which is very hard and tough under the hammer. The white portion seems to have consisted of anhydrite, which, on the surface especially, has become hydrated, and in expanding has split and separated the intervening limestone, giving it the above-mentioned brecciated appearance; at any rate, the intervening alabaster-looking substance, gives the qualitative tests of hydrated calcic sulphate. Near the upper

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part of the specimen, the colour becomes slightly grey probably from a small quantity of graphitic carbon.

Microscopically, the rock is seen, with natural light, to be composed of minute grains suspended in an amorphous transparent matrix and collected in strata. In polarised light, however, this apparently homogeneous matrix breaks up into a patchy-looking mass by polarising in various shades of grey in a very thin section. Scattered very sparsely, are a few grains of white peridote, and with a little greater abundance, smaller ones. The presence of this latter mineral, taken together with that of graphitic matter, is sufficient evidence of the metamorphic origin of the composition of this rock, since otherwise it might be supposed to consist of some sedimentary deposit in which calcic sulphate and carbonate had been alternately thrown down.

(51). Is a highly saccharoidal marble, most of the constituent grains being a millimetre in diameter. About half the specimen is white in colour, but exhibits rather markedly fine stratification as indicated by bands of whiter or more opaque colour, which prove, on microscopical examination, to depend on enclosure within and between the calcite grains of white peridote, and minute octahedra of brucite pseudomorphous, after periclase. In the other half of the specimen are well marked bands of brown grey and dirty greenish blue colour. These bands are composed principally of an abundant admixture of periclase and resultant brucite, together with more peridote. The periclase grains rarely exceed an eighteenth or twentieth of a millimetre in diameter, and possess a faint dirty greenish tinge. They remain clear between crossed nicols, but exhibit a granular structure, in consequence of which, they really have been evidently changed to brucite, resulting from their hydration. There is yet another still more interesting metamorphic change that has taken place, for some of the bands suddenly pass from the grey green to a blackish grey colour. This change is seen beneath the microscope to consist of the conversion of the periclase into black spinel. Although the stratum is as well marked in its limits as in the other parts of the specimen, the spinels have been arranged in laminæ contorted within itself, a condition not observable in the periclase portion of the same band, which, on the contrary, show parallelism with the planes of stratification. Some of the ex-periclase crystals are stained by limonitic matter, but only in isolated and irregular patches. That the change of the periclase is independent of peridote is proved by treating the rock with not too dilute acid, which dissolves the periclase and its alteration products, but not the peridote grains within the rock. The calcite of this

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specimen exhibits rather rarely either ribbon or lattice structure except on that side where the spinel exists, and therefore where the metamorphic action proceeded from, and consequently where it exerted a more powerful influence.

(47.) Resembles much in appearance the last specimen, except that the marble grains are still coarser. It is traversed about its middle by a brownish band which to the naked eye appears to be composed of minute ochreous spots. Microscopically, in the white marbly part, there are a few peridote grains to be seen, but near the coloured band are more numerous, and are accompanied by transparent though granular-looking octahedra, which in ordinary light appear homogeneous, but on crossing the nicols an isotropic black nucleus appears surrounded by an anisotropic crust, so that we can see the gradual conversion of periclase to brucite (Fig. 47, Plate XIV.). In some crystals, under a high power and polarised light, the periclase nucleus is seen to be composed of a trabecular network of that mineral. Treating the rock with dilute HCl., the residue consists of irregular grains of white peridote and octahedra of periclase, which seem to resist the solution, as had been noticed by Cossa in his researches. Some also show minute spots of strong double refraction that leave the suspicion on one's mind that they may in part be changed to peridote. Cossa ("Sulla Predazzite periclasifera del Monte Somma," Atti d. R. Accad. dei Lincei, Vol. IV., 2nd series, 1875-1876, p. 3) observed that the somewhat singular rock gave an alkaline reaction and afforded good reasons to show that the magnesia did not exist as a double carbonate with lime. Besides, he pointed out that the rock he examined contained much water of hydration as all the periclase nearly seems to have been converted to brucite.

(50). At first sight, this specimen resembles much No. 48, but looking closer at it, it exhibits a fine granular or feebly saccharoidal rock of dirty white colour, with contorted and faulted bandings in grey. Some of the bands are very coarsely crystalline, or more properly, consist of fissures lined by crystals of humite up to a millimetre in diameter, upon which are posed minute black grains of octahedral form as discernible with a magnifying glass.

Microscopically, we find the mass consists of small grains of dirty calcite, and the smaller dark bands to consist of minute octahedra of periclase, chiefly enveloped in the calcite grains. Many white peridotes occur, scattered throughout the rock, and in some cases enclose the octahedra of periclase within them. Along the larger bands the humite is seen polarising in very brilliant colours, and practically indistinguishable from the

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white peridote.[1] The spinels, which seem to be the last formed, are very small and usually badly crystallised. The periclases seem to be little, if at all, altered.

(44). This specimen is perhaps one of the most interesting, it illustrates how metamorphism, acting at right angles to the stratification planes, converts a bedded limestone into one that shows no traces of such mechanical arrangement by the introduction or increase in quantity of many minerals which, associated together, constitute perhaps the largest group of ejected blocks of Monte Somma. At the same time, it exhibits how, in some cases, the formation of Mierisch's zonal structure is quite independent of bedding. The composition of the specimen is as follows: (*a*) a band of coarse, friable, glistening, white saccharoidal marble, showing by size of grains distinct stratification,—this measures about one and a-half centimetres; (*b*) the same, but much finer grained,—this measures about three centimetres; (*c*) the last half centimetre becomes increasingly grey in colour from the presence of periclase and, possibly, peridote; (*d*) then there is a fibrous-looking band of probably white peridote, followed by more periclase-bearing rock, and then more white marble.

Band (*a*) passes at one end of the specimen into a very coarse saccharoidal marble. Band (*b*) is separated from the same material by a thin stratum of periclase-bearing material arranged at right angles to the bedding planes. On the contrary (*c*) still retains its character farther, but is eventually bent up and lost in the same mass of granular marble, and remaining bands follow the example of (*c*). Thus we have the well-marked stratified arrangement at one end of the specimen entirely obliterated, and a mineral aggregate representing it without any definite arrangement.

On the opposite side of the specimen this is much more marked, so that the white peridote band seems to have been in a state of fusion and to have been squeezed into the neighbouring mass so as to form a minute dyke. In fact, I strongly suspect that this band is not original but an intrusive one, being forced in as a juice, and setting up chemical changes along its borders, for it is here that the limestone is richest in oxides and silicates. The surface of the specimen towards the metamorphic focus is covered by a thick dark green crust of peridote, spinel, augite (?), and biotite, in the order that it occurs in the walls of drusy limestone as described by Mierisch (*loc. cit.* p. 121).

[1] Mierisch (*loc. cit.* p. 141) found the same difficulty. By isolating some of the grains a fluorine reaction can be easily obtained, and even with very small quantities the micro-chemical test with fluo-silicate of soda I found to be very characteristic.

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Conclusions.

Such are the specimens of stratified limestones which are to serve as clues to the remarkable series of reactions that have converted cretaceous limestones into a series of rocks that, by themselves, one would hardly dare to suppose once to have been nothing more than an impure dolomitic limestone. I do not doubt that it will be argued that changes that occur in such small specimens should not be used as a guide to what occurs in large masses. To this it may be answered that the greater number of chemical phenomena that occur in the mineral world can be studied on the smallest scale in the laboratory. But beyond this these very same metamorphic changes may be traced on a much grander scale amongst the ejected blocks of Monte Somma, and I propose to confirm and extend these few notes in another paper on the massive limestones and their derivatives.

Further, when we extend our investigations to the contact phenomena of such a region as the Tyrol, which are probably of less importance than what is really going on beneath Vesuvius, and from thence pass to areas of regional metamorphism, we are struck by the great similarity in the changes that have taken place. It must, however, be borne in mind that three important factors enter into the question, namely, the composition of the rock to be acted upon, that of the magma acting, and the time, circulation, and quantity of the latter. And equally imperative is it to remember that such rocks which reach the surface by denudation of the overlying materials have been exposed to so many fresh changes as sometimes to be no longer recognisable.

The changes that take place in an impure limestone seem to be, in the first place, the carbonisation of the bituminous contents with the conversion of them into graphite. Almost coincidentally re-crystallisation seems to have taken place, for what was an extremely fine-grained rock begins to approach the saccharoidal structure. This re-arrangement or re-crystallisation seems to have occurred without the rock having become fused, or even pasty, since the most delicate stratification, banding, faulting, and contortion structure is preserved. At this stage a few grains of peridote begin to make their appearance, chiefly as inclusions within the calcite crystals. The next process is the destruction of the graphite, and in some cases its apparent replacement by peridote, as in specimen No. 200. In the early stages of carbonisation the graphite exists between the grains, but later gets enclosed within them, as if they had undergone fusion. With the disappearance of the graphite, what remains

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is a more or less coarse-grained, dazzling white marble. This saccharoidal marble, containing more or less white peridote, passes somewhat abruptly into a mass of peridote and white pyroxine, wollastonite, or biotite. Why, sometimes it is one or sometimes another mineral that borders on the white marble, I feel inclined to attribute to the impurities in the original limestone in the absence of alumina, with a supply, though limited, of silica, with much lime and magnesia, so that either Forsterite or Monticellite may result, and, if much iron, even true Olivine may separate out. If only silica and lime are present, then we must look for Wollastonite. Likewise, the presence of fluorine may determine the crystallisation of Humite instead of Peridote. In the same way we understand how the other minerals may separate. Now, in a stratified limestone, some bands will be more argillaceous, silicious, ferriferous, or magnesian, or two or more of these impurities may abound, so that in a stratified rock of this kind, the minerals developed in one band will differ from those in another, as is so strikingly shown in specimen No. 41.

This metamorphism is selective only in the early stages, for (as in 36, 54, and 40) we have the silicate bands encroaching upon the intervening marble strata; whilst in 44, the well stratified portion, toward the metamorphosing focus, is fused (?) up into a fairly homogeneous mass of coarser grains and larger crystals of the same minerals as in the undisturbed part, together with the addition of others. Yet that the composition of the bands has a strong determining influence on the results is well illustrated in No. 51.

The order in which the new minerals seem to develop is the following:—

(1) Peridote, Periclase, Humite.
(2) Spinel, Mica, Fluorite, Galena, Pyrites, Wollastonite.
(3) Garnet, Idocrase, Nepheline, Sodalite, Felspar.
(4) Calcite (secondary).

Although in some cases there is an approach to the order of mineral species found in the druse walls described by Mierisch (*loc. cit.* p. 121), yet these are exceptional, and open up for our investigation a far wider field of facts.

It is evident that any researches as to the purely chemical changes that take place in the process of metamorphism would be useless in stratified limestones unless it were possible to know the composition of each band. It will therefore be better to consider these questions where treating of the massive limestones and their derivatives.

Then also, it is necessary to study the changes that have taken place in the minerals originally replacing the limestone.

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We have distinct evidence of the conversion of Periclase into Brucite, and of Peridote to a whitish fibrous mineral or Pilite (?) The Biotite, Nepheline, Felspar (?) and Peridote may be crowded with microliths, which there is good reason to believe consist of Pyroxene.

Another point of interest is that I have not so far noticed the presence of periclase in any rock where graphite could be detected. This might well be explained by the fact that so long as free carbon remained, the magnesia would be maintained as carbonate, and only on its loss of the CO_2 could it take up the SiO_2 to form forsterite, or, with the addition of lime, monticellite; or should silica be absent, to combine with any alumina and to separate as spinel.

Specimen 51 indicates, at any rate, that the latter result is subsequent to the former. Certainly 200 is curious, as showing an apparent displacement of the carbon grains by peridote, although it may be that that mineral simply occupies the spaces left by the disappearing carbon.

It is also necessary at the same time to remember the chemical relationship of carbon and silicon. Another point is, that in all probability the first minerals produced by metamorphism are elaborated from materials contained within the rocks themselves; but eventually other constituents are added, or are removed, by the circulation of water, by vapours, or by diffusion from neighbouring rock masses or igneous magma. Cossa found that he could reproduce periclase by heating for some hours magnesic sulphate and sodic chloride, and obtained still larger crystals by adding a little ferrous sulphate. This, however, is hardly likely to be the process of formation in the rocks beneath Vesuvius. Deville reproduced periclase by acting on magnesia by hydrochloric acid gas, and Daubrée by the action of magnesic chloride on lime. There is good reason to believe that it was by one or both of the latter processes that resulted in the production of periclase in the magnesian limestone, especially when we take into consideration the great abundance of hydrochloric acid and chlorides contained within the neighbouring incandescent lava of Vesuvius. The artificial reproduction of forsterite by Ebelmen probably is a near imitation of what occurred in its natural production.

In fine, we see a definite order of chemical changes occurring in jurassic and cretaceous limestone, which may convert that rock into a granitic mass of crystallised basic silicates and oxides, &c., which may in their turn by decomposition, give rise to a group of rocks in which the original constituents would be represented by serpentine and its varieties, Tremolite, Brucite, &c., an association which prevails amongst metamorphic rocks

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that are exposed at the surface by that series of precarious events constituting denudation.

With regard to the removal of the lime in these metamorphosed rocks, Mierisch (*loc. cit.* p. 187) supposes the excess to have been carried off as chloride by fumarolic action, and thinks that the small quantity deposited around fumaroles proof of such being the case. Without laying stress on the latter, we may admit that this is very probable; may it not, however, be that much of the lime is retained in the lava, being utilised in the formation of some or all the lime-bearing crystal components, whilst the HCl would volatilise, as we know it does do, very largely from the volcanic vent.

As Mierisch has to a great extent exhausted the description of the drusy limestones, it is proposed in the next paper to treat of the massive limestones, their alteration, metamorphism, and their derivatives.

EXPLANATION OF PLATES.

PLATE XIII.

Figure 32. Section of altered graphitiferous limestone. Magnif, 24 diameter. Light normal.

Figure 40. Section of metamorphosed limestone showing part of a silicate band, which is here composed chiefly of white pyroxene, a little biotite with all interspaces filled by calcite. Magnif, 24 diameter. Light normal.

Figure 41. Section of metamorphosed limestone. The part shown is the coarse crystalline broad band, in which is enclosed a much fissured crystal of perodite traversed by pilite, and surrounded and enveloped in calcite with well-marked lattice structure. Magnif, 24 diameter. Light normal.

PLATE XIV.

Figure 47. Section of coarse crystalline metamorphosed limestone. The sections show large grains of periclase (black), surrounded by a crust of breccite. Many small grains of peridote are visible and distinguishable by their lighter colour: one is seen enclosed within the periclase crystal just above the centre of the figure. Magnif, 24 diameter. Polarised light, nicols crossed.

Figure 54. Section of silicate part of specimen. The upper portion consists chiefly of biotite clear at the edges, but towards the centre crowded with microliths. One or two prisms of that

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mineral free from enclosures are visible in this preparation. The left lower half is composed of the felspar-like mineral remarkably clear, but including an increasing number of microliths towards the edge of the field. At its lower part it includes calcite crystals (seen faintly, whilst a large part, *i.e.*, the clear part) of the right lower half of the field consists of that mineral, though very dirty. Magnif, 24 diameter. Light normal.

Figure 161. Unknown mineral with zoned or fluted structure and microlithic nucleus. Above it are two crystals of peridote (slightly out of focus). Beneath microlithiferous biotite and a bit of nepheline (?). Magnif, 24 diameter. Light polarised, and nicols crossed.

Figure 200. Taken from the white marble part close to the grey portion. Large calcite grains, with well-marked lattice structure and cleavage planes, enclosing white peridote and graphite grains, either separately or the former enclosing the latter. Magnif, 24 diameter. Light normal.

PLATE XV.

Figure 200*b*. Silicate part of specimen. This preparation shows the grains of peridote without definite crystalline form, but arranged in a radiate form around nuclei, two of which are seen in the figure. Magnif, 24 diameter. Light normal.

Figure 205. Bituminous limestone traversed by veins of white calcite, and composed almost entirely of minute shells and foramenifera. Two nautiloid ones are very clearly seen to the left and downwards from the centre of the figure. To the right is seen in section a comparatively large trochiform shell. Magnif, 24 diameter. Light normal.

Figure 336. Fibrous pyroxene. The spaces between the fibres is principally filled by biotite, seen as patches of medium tint. Also vacant spaces are visible. Observe the irregular and broken up structure of the fibres. Magnif, 24 diameter. Light normal.

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APPENDIX.

PAPERS READ AND SPECIMENS EXHIBITED TO THE EDINBURGH GEOLOGICAL SOCIETY DURING SESSIONS 1888-89, 1889-90, 1890-1, 1891-2, and 1892-3.

SESSION 1888-89.

22*nd November* 1888.—Anniversary Address on Darwin's Geological Work. By Mr Ralph Richardson, F.R.S.E., *Vice-President.*

20*th December* 1888.—1. The Normal Micas: their Nature, &c. By Alex. Johnstone, F.G.S. 2. The Work of the International Geological Congress, London, Sept. 1888. By H. M. Cadell, F.R.S.E., *Hon. Sec.*

17*th January* 1889.—1. A Visit to the Morgan Gold-mining District of North Wales. By Dr W. G. Black. 2. The Detection of Antimony in Minerals. By Alex. Johnstone, F.G.S. 3. On a certain supposed High-Level Shell-bed in Easter Ross. By Mr Hugh Miller, F.R.S.E., F.G.S.

21*st February* 1889.—1. The Earthquake Shocks experienced in the Edinburgh District on Friday, 18th January 1889. By Mr Ralph Richardson, *Vice-President.* 2. Exhibition of Lavas and Pumice from the Canary Islands. By Mr John G. Reid, F.S.A.Scot. 3. Notes on the Discovered Sites of Flint Flakes in Devon and Cornwall. By Mr Nicholas Whitley, C.E.

21*st March* 1889.—1. The Succession of the Lower Carboniferous Series to the West of Edinburgh. By Mr John Henderson. 2. Notes on the Geology of Easter Ross. By Mr D. Cameron. 3. Exhibition of Specimens of Albertite from Strathpeffer. By Mr Hugh Miller, F.G.S. 4. The Eruptive Periods of the West Atlantic Islands. By Mr O. H. Howarth.

18*th April* 1889.—On Human Bones in a Scrobicularia-bed

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at Newton Abbot, Devonshire. By Mr William Pengelly, F.R.S.

2nd May 1889.—1. On the Modes of Occurrence of Faults. By Mr J. G. Goodchild, F.G.S. 2. Some Recent Improvements in the Identification of Minerals by the Blowpipe. By Mr Alex. Johnstone, F.G.S.

SESSION 1889-90.

21st November 1889.—Anniversary Address on the present position of Palæontological Science as regards Invertebrate Animals. By Prof. H. Alleyne Nicholson, M.D., D.Sc.

19th December 1889.—1. Obituary Notice of—1st, Dr R. Romanes, Rangoon; 2nd, Mr Andrew Young. By Mr H. M. Cadell, *Hon. Sec.* 2. On the Supposed Annelid Burrows of the Central Highlands. By Mr Peter Macnair. 3. Exhibition of Photographs of Silurian Fossils from the Pentlands. By Mr H. M. Cadell, *Hon. Sec.* 4. On some Abnormal Deposits of Limestone. By Mr J. G. Goodchild, F.G.S.

16th January 1890.—1. Our Coal Resources. By Prof. Edward Hull, F.R.S. 2. Notes on the Coal Question. By Mr H. M. Cadell, *Hon. Sec.*

20th February 1890.—1. Observations on the Geology of a part of the Puy de Dôme district of France. By Mr Ralph Richardson, F.R.S.E., *Vice-President.* 2. The Origin of Dolomitic Limestones. By J. G. Goodchild, *Librarian.* 3. The Composition and Origin of Magnesian Limestone and Dolomite. by Alex. Johnstone, F.G.S. 4. Exhibition of Metallic Ores from Damaraland. By Dr W. G. Black.

20th March 1890.—1. A Theory of the Devitrification of Igneous Rocks. By Alex. Johnstone, F.G.S. 2. A Partial Displacement *in situ* of some Boulders embedded in Till. By Hugh Miller, F.R.S.E.

17th April 1890.—1. Obituary Notice of Mr W. Hamilton Bell. By the *Hon. Sec.* 2. On the Occurrence of Birkhill Fossils at Innerleithen. By Jas. Wilson. 3. Notice of a Bed of Diabase in Jeffrey Street. By John Henderson. 4. Notes on some Irregular Forms of Bedding. By Mr J. G. Goodchild.

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1*st May* 1890.—1. On the Occurrence of Veins of Contorted Sedimentary Rock in a Bed of Porphyrite at Wolf's Hole Quarry, Bridge of Allan. By H. M. Cadell. 2. Exhibition of Flint Nodule with a centre of Trihedral Quartz Crystals. By Alex. Johnstone, F.G.S. 3. Evidences of Shearing Motion in Boulder Clay. By Jas. Wilson.

SESSION 1890-91.

27*th November* 1890.—Obituary Notice of David Milne Home, Esq., LL.D., late President of the Society. By Ralph Richardson, F.R.S.E.

18*th December* 1890.—Anniversary Address on Landscape Geology. By Mr Hugh Miller, F.R.S.E., F.G.S., *Vice-President.*

15*th January* 1891.—1. The Silurian Basin of South-West Mayo and North-West Galway. By G. H. Kinahan, M.R.I.A. 2. The Granitic and Schistose Series of West Galway. By G. H. Kinahan. 3. Exhibition of a Core from a Diamond Boring near Binny Craig, with Veins of Petroleum. By H. M. Cadell, *Hon. Sec.*

19*th February* 1891.—1. Obituary Notice of Dr James Croll, F.R.S. By John Horne, F.R.S.E. 2. An Outlier of Old Red in Mid-Ross-shire. By Wm. Morrison, M.A. 3. Exhibition of Gold-bearing Rocks from South Africa and Australia. By Jas. Currie, M.A. 4. Exhibition of a Lepidodendron Stem embedded in Basalt from Bo'ness Coalfield. By H. M. Cadell.

19*th March* 1891.—1. The Inverness Earthquake of 1890. By Hugh Miller, F.G.S., *Vice-President.* 2. The Scottish Earthquakes of 1889, 1880, 1889, and 1890. By Ralph Richardson, F.R.S.E.

7*th May* 1891.—1. *Homacanthus Borealis* from Caithness. By W. T. Kinnear. 2. The Discovery of a Whale's Vertebra in a cutting at Leith. By Geo. Craig. 3. Exhibition of Metallic Minerals. By Jas. Currie, M.A.

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SESSION 1891-92.

18*th November* 1891.—Anniversary Address: Supposed Causes of the Glacial Period. By Prof. James Geikie, D.C.L., LL.D., F.R.S., *President.*

17*th December* 1891.—1. On the Old Lakes of Edinburgh. By H. M. Cadell, F.R.S.E., *Hon. Sec.* 2. Exhibition of Photographs of Microscopic Sections, &c., of Dolorite from Whistlefield, Loch Long. By Mr William Forgan. 3. Notes on a Visit to the International Geological Congress at Washington in 1891. By H. M. Cadell, F.R.S.E., *Hon. Sec.*

21*st January* 1892.—Lecture on a Visit to the Yellowstone National Park, Rocky Mountains, Great Salt Lake and Grand Canyon of the Colorado River. By H. M. Cadell, F.R.S.E., *Hon. Sec.*

18*th February* 1892.—1. Obituary Notice of Sir Andrew Crombie Ramsay, F.R.S. By Prof. James Geikie, F.R.S., *President.* 2. On the Elgin Sandstones and their Fossil Remains. By Mr J. G. Goodchild, F.G.S. 3. On a Building Stone Quarry at Ravelstone. By Mr R. Richardson, F.R.S.E. 4. Notes on a Flood in the Tweed on 21st September 1891. By Mr R. Richardson, F.R.S.E.

17*th March* 1892.—1. On a recently exposed Section on the east side of Blackford Hill. By Mr Bernard Stracey. 2. Exhibition of Microscopic Sections of Picrite, &c. By Mr William Forgan.

21*st April* 1892.—1. Notes on the Occurrence of Moraines later than the 50-foot Beach in the North-West Highlands. By Mr L. W. Hinxman, B.A. 2. Exhibition of Blocks of Wood from the Boulder Clay at Waterstone, near Linlithgow. By Mr H. M. Cadell, F.R.S.E., *Hon. Sec.* 3. Notes on a Specimen of *Homosteus Milleri.* By Mr W. Tait Kinnear. 4. Exhibition of Chabazite from Victoria. By Mr James Currie, M.A., *Asst.-Librarian.*

5*th May* 1892.—1. The Building Stones used in Edinburgh: their Geological Sources, &c. By Mr George Craig, Architect. 2. Notes on the Physical Properties of some of the Edinburgh Building Stones. By Prof. T. Hudson Beare, University College, London.

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SESSION 1892-93.

17*th November* 1892.—Anniversary Address: On Geological Changes wrought by Man within the Forth Basin. By Mr H. M. Cadell, F.R.S.E., *Hon. Secs.*

15*th December* 1892.—Lecture on Etna. By Mr J. G. Goodchild, F.G.S.

19*th January* 1893.—1. The Glaciation of the Upper Engadine. By Prof. James Geikie, F.R.S., *President.* 2. Sections exposed in the Railway Cutting at Barnton. By Mr John Henderson.

16*th February* 1893.—1. The Splint Coal of Lanarkshire and its Organic Remains. By Dr John Hunter of Braidwood. 2. Exhibition of Fish Remains from the Braidwood Collection. By Dr Hunter.

16*th March* 1893.—The Contents of a Shell Mound at Tongue at Sutherland. By Mr John Horne and Mr Benjamin N. Peach, H.M. Geological Survey. 2. The Occurrence of Shelly Boulder Clay at North Ronaldshay. By Messrs Peach and Horne.

4*th May* 1893.—1. On the Minerals occurring in the Section of Corstorphine Hill at Barnton. By Mr J. G. Goodchild. 2. On the Ejected Blocks of Monte Somma. By Prof. H. J. Johnston-Lavis of Naples, *Foreign Corresponding Fellow.*

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CORRESPONDING SOCIETIES AND INSTITUTIONS.

(*Corrected to 16th March* 1893.)

I. HONORARY FELLOWS.

(*The number is limited by Law to Twelve.*)

His Grace THE DUKE OF ARGYLL, K.G., K.T., D.C.L., F.R.S., Inverary Castle, Argyllshire, and Argyll Lodge, Campden Hill, London. *Patron of the Society.*[1]

Sir ARCHIBALD GEIKIE, D.C.L., LL.D., F.R.S., F.G.S., Director General of the Geological Survey of the United Kingdom, Jermyn Street, London, S.W. *President of the Society*, 1868-74.

THOMAS B. JOHNSTON, F.R.S.E., F.S.A. Scot., of Messrs W. & A. K. Johnston, Geographical Publishers, Edina Works, Easter Road.

Sir JOHN WILLIAM DAWSON, K.C.M.G., LL.D., F.R.S., &c., Principal and Vice-Chancellor of M'Gill University, Montreal, Canada.

Professor EDWARD HULL, LL.D., F.R.S., F.G.S., late Director of the Geological Survey of Ireland, 20 Arundel Gardens, Notting Hill, London, W.

Professor CHARLES LAPWORTH, LL.D., F.R.S., F.G.S., Mason's College, Birmingham.

Professor H. ALLEYNE NICHOLSON, M.D., D.Sc., F.G.S., Aberdeen University.

II. ORDINARY FELLOWS.

Those Fellows who have become "Life Members" have an asterisk attached to their names. The dates indicate when the Fellows were elected.

*Adam, Robert, F.S.A. Scot., City Chamberlain (1884).

Adams, William, 28 Ashton Terrace, Hillhead, Glasgow, *Councillor* (1880).

Aitken, J. Edington, Breadalbane Cottage, Fisherrow, Musselburgh (1885).

Anderson, William, Geological Survey of N.S.W., MacQuarie St., Sydney, N.S.W. (1884).

*Archibald, John, Devonvale, Tillicoultry (1868).

Armstrong, Wm., M.E., Wingate, Durham (1869).

Bainbridge, F. Gascoigne, I.B.E.A.Coy., Zanzibar (1889).

*Balfour, Isaac Bayley, D.Sc., F.R.S.E., Professor of Botany, Edinburgh University (1874).

Bartholomew, John G., F.R.S.E., 12 Blacket Place (1884).

[1] His Grace was elected Patron in 1875. The former Patrons were Sir Roderick Murchison and Sir Charles Lyell, who successively held the appointment until their death.

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Barton, John Frater, 5 Mansionhouse Road (1888).
Beaton, Angus J., Engineer's office, London & North Western Railway, Marsden, Yorkshire (1891).
Bell, Robert, of Clifton Hall, Ratho (1866).
*Black, Dr W. G., 2 George Square (1873).
*Blyth, Rev. Thos. Allen, D.D. (Oxon.), M.A., Ph.D. (Gött.), Vicar of Stoke, Stoke Park, Coventry (1864).
Bones, Arthur A., High Street, Coventry (1893).
*Bray, Henry Adam, M.D., Market Rasen, Lincolnshire, (1878).
*Brooke, Wilton, F.S.Sc., Stairfoot, Barnsley (1892).
Bryce, Wm., M.D., 31 Charlotte Square (1880).
Buchanan, John, C.E., 24 George Street (1868).
Cadell, Henry Moubray, of Grange, B.Sc., F.R.S.E., J.P., Grange, Bo'ness; Caledonian United Service Club, Queen Street, *Honorary Secretary* (1880).
Cairns, Robert, High School, Dunfermline (1889). *Councillor.*
Calderhead, Robert, 5 Ivy Terrace (1893).
*Cameron, David, Schoolhouse, Daviot, Inverness (1881).
Carey, William, Struan Villa, Portland Road, Kilmarnock (1866).
Carey, William, Manager Bridgeness Colliery, Bo'ness (1890).
*Carmichael, T. D. Gibson, yr. of Skirling, Castlecraig, Dolphinton (1887).
Clark, Allan, E.L., Master of Works, Edinburgh University (1887).
Clark, James, Ormiston (1892).
Claypole, Professor E. W., B.A., D.Sc., F.G.S., Akron, Ohio, U.S.A. (1887).
Cooper, Frank A., Head Master Oak Grove School, Musuri, India (1892).
*Corke, H. C., 178 High Street, Southampton (1887).
Corstorphine, George S., B.Sc., Geological Department, University of Edinburgh (1893).
*Craig, George, Architect, 85 Duke Street, Leith (1882).
Crunden, Robert H., Fernlea, The Shrubbery, Plaistow, Essex (1887).
Currie, Dr Alex. John, 219 Onslow Drive, Dennistoun, Glasgow (1893)
*Currie, James, junr., M.A., (Cantab.), Larkfield, Golden Acre, *Assistant Librarian* (1888).
*Deans, P. D., 62 Great King Street (1876).
*Dickson, H. N., 3 Marlborough Road, Plymouth (1884).
Drummond, William, S.S.C., 21 Charlotte Square (1868).
Dudgeon, Patrick, of Cargen, F.R.S.E., Cargen, Dumfriesshire (1887).
*Fairley, John G., Joiner, West Calder (1889).
Farquharson, Rev. Alexander, Belgrave Road, Oldham (1880).
Farquharson, Thomas Ker, Accountant, 100 Thirlestane Road (1875).
Ferguson, John, 15 Brighton Place, Portobello (1863).
*Ferguson, William, of Kinmundy, Mintlaw, Aberdeenshire, F.R.S.E., F.L.S., F.G.S., University Club, Princes St. (1876).
Firth, Wm. M., 19 Montpelier (1888).
Fleming, Andrew, M.D., F.R.S.E., Deputy Surgeon-General H.M. Indian Army, 8 Napier Road, Merchiston (1875).
Forgan, William, 13A Bristo Place, *Treasurer* (1889).
*Forrester, Robert, U.S. Inspector of Mines for Utah, Castle Gate, Utah, U.S.A. (1887).
*Fraser, Alexander, Canonmills Lodge (1869).
*Fraser, Charles, B.A., 13 Greenhill Place (1882).
*Fraser, James, C.E., 100 Castle Street, Inverness (1881).
Fraser, William, Consulting Director, Pumpherston Oil Company, Ld., 24 St Vincent Place, Glasgow (1882).
Geddes, Charles D., M.E., 8 Douglas Crescent (1889).

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Geikie, Prof. J., D.C.L., LL.D., F.R.S., 31 Merchiston Avenue, *President* (1891).
Gibb, Philip B., M.A., 14 Picardy Place (1880).
Gloag, Rev. Paton J., D.D., 28 Regent Terrace (1887).
Goodchild, J. G., F.G.S., H.M. Geological Survey, Museum of Science and Art, Edinburgh, *Librarian* (1889).
Grant, John, M.A., Glenfiddich Distillery, Dufftown (1889).
Gunn, John, F.R.S.G.S., 4 Parkside Terrace (1888).
Haigh, Wm. R., 26 Summerside Street, Leith (1892).
Hamilton, Robert, Trinity Lodge, Trinity (1884).
Hardie, David, Bavelaw Castle, Balerno (1887).
*Henderson, John, 10 Wellington Place, Leith (1862).
Henderson, Joseph J., F.R.S.G.S., U.S. Engineers' Office, New York, U.S.A. (1889).
Hinxman, Lionel W., B.A., H.M. Geological Survey (1890).
Hogg, Andrew, 7 Great Stuart Street (1887).
*Hood, Archibald, Coalmaster, Whitehill Colliery, Lasswade (1869).
Horne, Peter, Jeweller, Meuse Lane (1889).
Horne, John, F.R.S.E., F.G.S., H.M. Geological Survey (1891). *Vice-President.*
*Hunter, John R. S., LL.D., D.Sc., Daleville, Carluke (1862).
Jeffrey, David, 14 Randolph Crescent (1867).
*Jenner, Charles, F.R.S.E., Easter Duddingstone Lodge, Portobello (1867).
Johnstone, John A., 7 Annandale Street (1892)
*Jolly, William, F.R.S.E., H.M. Inspector of Schools, Greenhead House, Govan (1867).
Jones, James, Manager Dalmeny Oil Works (1889).
Jones, William J., B.A., Principal of the College, Goole, Yorkshire (1893).
*Keith, Alexander, *c/o* Lewis Taylor, Nassau, Bahamas (1884).
*Kellock, Robert, Glendyne Cottage, Joppa (1881).
Kilgour, T. W., 4 East Brighton Crescent, Portobello (1874).
Kinnear, David, 20 Iona Street, Leith (1893).
Kinnear, W. Tait, Forss, Thurso (1881).
*Knott, C. G., M.A., D.Sc., 2 Lauriston Park (1883).
Landale, Andrew, Comely Place, Dunfermline (1864).
Livesay, William, M.D. Edin., Sudbury, Derby (1869).
Livingston, Josiah, 4 Minto Street (1867).
*Loudon, W., 14 Belgrave Crescent (1886).
Lumsden, Alexander, M.E., Addiewell Oil Works, West Calder (1865).
*Macadam, W. Ivison, F.C.S., F.I.C., Lecturer on Chemistry and Analytical Chemist, School of Medicine, Surgeons' Hall, Professor of Chemistry, New Veterinary College, Lady Road, Craigmillar Park (1878).
Macalpine, A. N., B.Sc. Lond., Lecturer on Botany, School of Medicine (1884).
M'Auslane, William T., LL.D., 101 St Vincent Street, Glasgow (1888).
M'Cormick, Rev. W. T., F. R. G. S., Vicar of St Matthews, Brighton (1891).
M'Ewan, William, M.P., 25 Palmerston Place (1878).
MacIntosh, Hugh, 47 Warrender Park Road (1893).
Mackay, Æneas J. G., M.A., LL.D., Advocate, 7 Albyn Place (1867).
Mackay, Alex., LL.D., 13 Warriston Cres., Edinburgh (1892).
*Mackenzie, John F., C.E., H.M. India Service, 11 Nile Grove, Morningside (1873).
M'Lauchlan, John D., M.E., 21 Young Street (1889).
*M'Lagan, P., M.P., F.R.S.E., Calder Hall, Midcalder (1875).
*Marshall, W. H., of Callander, M.A., W.S., 25 Heriot Row (1875).
*Maughan, Edward, Inland Revenue Office (1874).
*Maxwell-Stuart, Herbert Constable, of Traquair, J.P., D.L., Innerleithen, Peeblesshire (1888).

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*Melven, William, M.A., 32 Gibson Street, Hillhead, Glasgow (1878).
*Melvin, James, 43 Drumsheugh Gardens (1868).
Menzies, H. F. (1889).
Miller, Hugh, F.R.S.E., F.G.S., H.M. Geological Survey (1888). *Vice-President.*
Miller, William, Merchant, Bo'ness (1881).
Morrison, William, M.A., 96 Viewforth (1884).
Oliver, J. S., 12 Greenhill Park (1879).
*Omond, R. Traill, Ben Nevis Observatory and 43 Charlotte Square (1881).
*Ormiston, Archibald R., 203 St Vincent Street, Glasgow (1866).
*Panton, George A., F.R.S.E., 73 Westfield Road, Edgbaston, Birmingham (1862).
*Powrie, James, of Reswallie, F.R.S.E., F.G.S., Reswallie, near Forfar (1867).
*Prentice, Thomas, Mining Manager, Addiewell, West Calder (1877).
Richardson, Adam B., F.S.A. Scot., 16 Coates Crescent (1884).
*Richardson, Ralph, W.S., F.R.S.E., 10 Magdala Place (1866).
Ritchie, James, C.E., Perth (1867).
Rix, Rev. Alfred H., LL.D., Primrose Hill, Bradford (1889).
Robertson, Charles, Redfern, Colinton Road (1887).
Robinson, E. C., Hollybush Works, Bethnal Green, London, E. (1882).
Romans, John, C.E., 30 St Andrew Square (1867).
*Sartori, Lieut. Florindo Florio, Scuola di Guerra, Turin (1893).
*Semple, Andrew, M.D., Hon. Dep. Surgeon-General, A.M.S., U.S. Club, Queen Street (1882).
Simpson, James, Asst. Curator, Anatomical Museum, New University Buildings, Park Place (1884).
Souden, John, 89 Marchmont Road (1893).
Sprague, T. B., M.A., F.R.S.E., 29 Buckingham Terrace (1878).
Stalker, Robert B., 6 West Claremont Street (1888).
Stevenson, W. Grant, A.R.S.A., 63 Haymarket Terrace (1888).
*Stevenson-Hamilton, Col. James, Braidwood, Carluke (1865).
*Stewart, D. R., Chemist, Broxburn (1876).
Stracey, Bernard, 45 Fountainhall Road (1892).
*Sturman, Edward A., M.A., LL.D., 160 Holland Road, Kensington, London, W. (1870).
*Sturrock, Peter, C.E., Kilmarnock (1866).
Sutherland, J., F.R.G.S., Schoolhouse, Mid Clyth, Wick (1888).
*Sutton, William, LL.D. (1871).
Tait, Adam, 28 Craigmillar Park (1881).
Tellet, Frederick S., L.R.C.S.I., Auburn House, Ramsay, Isle of Man (1889).
*Thin, James, Bookseller, 55 South Bridge (1867).
Turnbull, James, Printer, 14 Thistle Street (1867).
Waddell, George, 4 St Andrew Square (1884).
*Wallace, Thomas D., F.S.A. Scot., Rector of High School, Elleralie, Inverness (1879).
Wilson, Alexander Grant, A.R.S.M., Durievale, Fife (1889).
*Wilson, Charles Monck, M.A (1871).
Wilson, Greg, M.A., B.D., Weitlands, Falkirk (1891).

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III. ASSOCIATES.*

(The dates indicate year of election.)

Brown, Robert, M.A., Ph.D., F.R.G.S., Fersler, Rydal Road, Streatham, London, S.W. (1875).

Brown, Rev. Thomas, D.D., F.R.S.E., 16 Carlton Street (1874).

Coyne, Roderick A. F. A., C.E., Water Trust Offices, Royal Exchange (1893).

Crosskey, Rev. Henry W., F.G.S., 117 Gough Road, Edgbaston, Birmingham (1864).

Heddle, Prof. M. Forster, St Andrews (1884).

Hunter, Rev. Robert, M.A., F.G.S., Forest Retreat, Staples Road, Loughton, Essex (1869).

Judd, John W., F.R.S., Professor of Geology Royal College of Science, S. Kensington, S.W. (1875).

Kinahan, G. H., M.R.I.A., Woodlands, Fairview, Dublin (1875).

Lewis, Rev. Jas. H., D.C.L., Mus. Doc., Silvermead, Twickenham, London, S.W. (1893).

Pengelly, William, F.R.S., Lamorna, Torquay (1888).

Prestwich, Joseph, M.A., F.R.S., Shoreham, Sevenoaks, Kent (1875).

Rudler, Frederick W., F.G.S., Curator Museum of Practical Geology, Jermyn Street, London, S.W. (1875).

Rupert Jones, Professor T., F.R.S., 10 Uverdale Road, King's Road, Chelsea, London, S.W. (1884).

Somervail, Alexander, 59 Fleet Street, Torquay (1881).

Sturrock, Thos., Auchtermuchty (1884).

Taylor, Andrew, F.C.S., Mineral Surveyor, 11 Lutton Place (1867).

Thompson, D'Arcy Wentworth, M.A., F.L.S., Professor of Biology, University College, Dundee (1881).

Whitley, Nicholas, C.E., Penarth, Truro, Cornwall (1865).

Wilson, James, *Border Record*, Galashiels (1884).

Woodward, Henry, LL.D., F.R.S., F.Z.S., British Museum, Natural History, S. Kensington, S.W. (1869).

Wünsch, Edward A., F.G.S., Carharrack, Scorrier, Cornwall (1866).

Young, John, F.G.S., Hunterian Museum Glasgow University (1867).

IV. LADY ASSOCIATE.

Milne-Home, Miss Grace, 12 York Place (1893).

V. FOREIGN CORRESPONDING FELLOWS.

(The dates indicate year of election.)

I. Europe.

Austria.

Böhm, Dr August, k.k. technische Hochschule, Alterstrasse 4, Vienna IX. (1893).

Ettingshausen, Baron Constantin, Professor University of Gratz (1893).

Fritsch, Professor A., Prague, Bohemia (1881).

Penck, Professor Albrecht, Ph.D., University of Vienna (1893).

Suess, Professor Eduard, Ph.D., University of Vienna (1893).

Belgium.

Dupont, Edouard, Director au Musée royale d'histoire naturelle de Belgique, 102 Rue Terre-neuve, Brussels (1893).

* Law XVI. enacts, "The Society shall have power to elect by ballot, as *Associates*, gentlemen distinguished for their Scientific attainments and researches, particularly in any department of Geology, or who may have acquired claims on the Society by aiding the furtherance of its objects.

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De Koninck, Laurent Guillaume, M.D., Professor of Chemistry and Palæontology University of Liége (1881).

Grossart, E., 26 Rue de la Madeleine, Brussels (1869).

Renard, Professor A., Ghent (1878).

Van den Broeck, E., Musée royale d'histoire naturelle, Brussels (1893).

Denmark.

Johnstrup, Professor Johannes Frederik, University of Copenhagen (1869).

Steenstrup, Professor Dr Japetus S., University of Copenhagen (1869).

France.

Barrois, Professor Dr Chas., University of Lille, Rue des Fleurs 1, Lille (1893).

Bertrand, Professor Marcel, 101 Rue de Rennes, Paris (1893).

Daubrée, Professor Auguste, 254 Boulevard St Germain, Paris (1893).

Fouqué, Professor F., Collège de France, Paris (1893).

Gaudry, Prof. Albert, Museum d'histoire naturelle, Paris (1893).

Margerie, Professor Emm. de, 132 Rue de Grenelle, Paris (1893).

Germany.

Bunsen, Professor Dr R. W., University of Heidelberg (1884).

Credner, Professor Dr Hermann, University of Leipzig (1893).

Geinitz, Professor Dr Hans Bruno, University of Dresden (1869).

Richthofen, Baron F. von, Berlin, W. (1893).

Rosenbusch, Professor Dr H. F., University of Heidelberg (1884).

Sandberger, Professor Dr F. von, University of Würtzburg, Bavaria (1869).

Schumacher, Professor Dr, Director Geol. Landesanstalt Elsass-Lothringen, Strassburg (1893).

Wahnschaffe, Professor Dr, Kgl., Landesgeologe, Chausseestrasse 52A iii. Berlin, N. (1893).

Zirkel, Professor F., 15 Thalstrasse, Leipzig (1869).

Zittel, Professor Dr Karl G. von, University of Munich (1893).

Italy.

Capellini, Professor Giovanni, LL.D., Senatore del Regno, Bologna (1893).

Johnston-Lavis, H. J., M.D., M.R.C.S., F.G.S., &c., Professor of Vulcanology, University of Naples, 7 Chiatomone, Naples (Nov. to May), and 5 Princes Square, Harrowgate (June to Oct.) (1893).

Norway.

Blytt, Professor Axel, University of Christiania (1893).

Brögger, Professor W. C., University of Christiania (1893).

Reusch, Dr Hans, Director Geol. Survey of Norway, Christiania (1893).

Rink, Dr H., 7 Keysergade, Christiania (1887).

Russia.

Kokscharow, Major-Gen. N. von, St Petersburg (1869).

Nikitin, Serge, Géologue en chef du Comité Geologique de la Russie (1893).

Sweden.

Geer, Baron Gerard de, Geological Survey, Stockholm (1893).

Lindström, Professor Gustav, State Museum, Stockholm (1884).

Nathorst, Dr Alfred Gabriel, Professor, Acad. of Sciences, Stockholm (1884).

Torell, Professor Otto M., Director Geol. Survey of Sweden, Stockholm (1869).

Switzerland.

Heim, Professor Alb., Hottingen, Zürich (1893).

Pasquier, Dr L. Du, Rochette, Neuchatel (1893).

Renevier, Professor G., Lausanne (1893).

Rütimeyer, Professor L., Basel (1893).

II. Asia.

India.

Foote, R. B., Ivy Cottage, Yercand, Madras Presidency.

Griesbach, C. L., C.I.E., Geological Survey Office, Calcutta.

Japan.

Milne, Professor J., Tokio.

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III. AMERICA.

Canada.

Dawson, Dr G. M., Geological Survey, Ottawa (1893).

United States.

Blake, Professor William P., State Department, Newhaven, Connecticut (1866).
Brooks, Major T. B., Newburgh, New York (1876).
Brush, Professor G. J., Yale, Newhaven, Connecticut (1893).
Branner, Professor J. C., Leland Stanford Junior University, Palo Alto, Santa Clara Co., California (1893).
Chamberlin, President T. C., University of Chicago (1893).
Dana, Professor E. S., Newhaven, Connecticut (1893).
Davis, Professor W. M., Harvard, Cambridge, Mass. (1893).
Gilbert, Professor G. K., U.S. Geol. Survey, Washington D.C. (1888).
Shaler, Professor N. S., Harvard, Cambridge, Mass. (1893).
Stevenson, Professor John J., University of New York (1892).
Whitney, Professor J. D., Cambridge, Mass. (1866).

IV. AFRICA.

Hatch, Dr F. H., F.G.S., Johannesburg (1893).
Stewart, Thomas, C.E., F.G.S., Cape Town (1893).

V. AUSTRALASIA.

New South Wales.

Liversidge, Professor A., Sydney (1893).

Queensland.

Jack, R. L., F.G.S., Director Geological Survey of Queensland, Townsville, Queensland (1878).

Tasmania.

Johnston, R. M., Hobart (1893).

Victoria.

M'Coy, Frederick, Professor of Natural History, Melbourne University (1866).

LEARNED SOCIETIES AND INSTITUTIONS IN CORRESPONDENCE WITH THE SOCIETY.

I. SCOTLAND.

Edinburgh.

Royal Society.
Society of Antiquaries of Scotland.
Botanical Society.
Scottish Meteorological Society.
Royal Physical Society.
Royal Scottish Geographical Society.
Advocates' Library.
Signet Library.
University Library.

Glasgow.

Geological Society.
Natural History Society.
Philosophical Society.

Berwickshire.

Naturalists' Club.

Perth.

Perthshire Natural History Soc.

Dumfries.

Dumfries and Galloway Natural History and Antiquarian Soc.

Inverness.

Scientific Society and Field Club.

Stirling.

Natural History and Archæological Society.

II. ENGLAND.

London.

Royal Society.
Geological Society.
Geologists' Association.
Royal Geographical Society.
British Museum.
Palæontographical Society.
British Association.
Patent Office.

Oxford.

Bodleian Library.

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Cambridge.
University Library.

Manchester.
Geological Society.
Literary and Philosophical Soc.

Liverpool.
Geological Society.
Geological Association.
Literary and Philosophical Soc.

Leeds.
Geological Association.
Philosophical and Literary Soc.

Norwich.
Norfolk and Norwich Naturalists' Society.

York.
Yorkshire Philosophical Society.
Yorkshire Geological and Polytechnic Society.

Birmingham.
Mason College.
Philosophical Society.

Bristol.
Naturalists' Society.

Truro.
Royal Institution of Cornwall.

Penzance.
Royal Geological Society of Cornwall.

Warwick.
Warwickshire Natural History Society.

Newcastle-on-Tyne.
Northumberland and Durham Natural History Society.

Watford, Hertfordshire.
Natural History Society.

Brighton.
Natural History Society.

Buckhurst Hill (Essex).
Epping Forest and County of Essex Field Club.

Eastbourne.
Natural History Society.

Falmouth.
Royal Cornwall Polytechnic Soc.

Stafford.
Naturalist Field Club.

III. IRELAND.

Dublin.
Library of Trinity College.
Royal Irish Academy.
Royal Geological Society of Ireland.
Royal Society.

Belfast.
Naturalists' Field Club.

IV. FRANCE.

Paris.
Académie des Sciences.
Société Géologique de France.
Department for Public Instruction.

Lyons.
Société Linnéenne de Lyon.

Amiens.
Société Linnéenne du Nord.

Lille.
Société Géologique du Nord.

V. BELGIUM.

Brussels.
Académie Royale de Belgique.
Department of Mines.
Musée Royale d'Histoire Naturelle de Belgique.
Carte Géologique de la Belgique.

Liége.
Société Royale des Sciences.
Société Géologique de Belgique.

VI. SWITZERLAND.

Geneva.
Société de Physique et d'Histoire Naturelle.

Lausanne.
Société Vaudoise de Sciences.

Zürich.
Naturforschende Gesellschaft.

VII. ITALY.

Rome.
Reale Comitato Geologico d'Italia.
R. Accademia dei Lincei.

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Florence.
R. Societa Geologica d'Italia.

Turin.
R. Accademia delle Scienze.

Venice.
R. Instituto Veneto di Scienze, Lettere, ed Arti.

Pisa.
Societa Toscana di Scienze Naturali.

Palermo.
Reale Accademia.

Naples.
Reale Societa.

VIII. AUSTRIA-HUNGARY.

Vienna.
K. K. Akademie der Wissenschaften.
K. K. Zoologisch-Botanische Gesellschaft.
K. K. Naturhistorisches Hofmuseum.

Budapest.
National Museum of Hungary.

Brünn.
Naturforschende Verein.

Innsbruck.
Naturwissenschaftlich-Medizinischer Verein.

IX. GERMANY.

Munich.
K. bayer. Akademie der Wissenschaften.

Heidelberg.
Naturhistorisch-Medicinischer Verein.

Dresden.
Naturwissenschaftliche Gesellschaft "Isis."
Verein für Erdkunde.

Leipzig.
K. Gesellschaft der Wissenschaften.

Braunsweig.
Naturwissenschaftlicher Verein.

Giessen.
Oberhessische Gesellschaft.

Freiburg, Baden.
Naturforschende Gesellschaft.

Tübingen.
Verein für Vaterländische Naturkunde.

Halle.
K. Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher.

Berlin.
K. Preuss. Geologischer Landesanstalt und Bergakademie.
Gesellschaft für Erdkunde.

Königsberg.
Physikalisch-Oekonomische Gesellschaft.

Bremen.
Naturwissenschaftlicher Verein.

X. DENMARK.

Copenhagen.
Royal Danish Academy.
Royal University.

XI. NORWAY.

Christiania.
Royal University.
Norwegian North Atlantic Expedition.

Bergen.
Library of the Museum.

Tromsö.
Tromsös Museum.

Trondhjem.
Royal Scientific Society of Norway.

XII. SWEDEN.

Stockholm.
Kongl. Svenska Vetenskaps-Akademien.

Upsala.
Regia Societas Scientiarum.

Lund.
Library of the University.

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XIII. Spain.

Madrid.

Reale Academia de Ciencias Exactas.

XIV. Russia.

Moscow.

Société Impériale des Naturalistes.

Kieff.

Société des Naturalistes.

XV. Canada.

Montreal.

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